WARREN H. FISHER, Project Engineer, Patron Systems

Design Trends and Concepts as Applied to Private Wire Telegraph Engineering

Continuous improvement in telegraph engineering techniques is well illustrated in the rapid postwar development of private switching systems for both message transmission and data processing. Not only have the various operating components of these systems been kept under critical review but in addition the arrangement, interconnection and cabinetry for component units have been consistently bettered.

THE TECHNOLOGY of telegraph communications 1956 is producing rapidly growing, complicated equipment and circuit networks requiring closely integrated skills and widely diversified approaches to a common end-point—namely, speed and accuracy in performance.

In this respect, communications today is little different from almost all other phases of our era. Examine the everyday things about us in the U. S. A. and compare what we see with those of a relatively few years ago. The average automobile has gone from the use of 65-85-hp engines to 185-225-hp engines; the commercial aircraft from speeds of 200-300 mph to 450 mph (and soon jets at approximately 650 mph); the long-distance telephone operator has in many offices been replaced by fully automatic dialing apparatus and the radio more often than not has been replaced by television in the average home. Even space travel is no longer spoken of with a tongue-in-cheek attitude. Western Union engineering is constantly pressing forward in pace with all other technology.

A splendid example in Western Union of the modern approach to engineering advancement is in the "Private Wire" or "Patron System" organization. Here telegraphic communications engineering must, of necessity, keep pace with the business world as well as the governmental and armed services techniques. Customers' telegraphic communications equipment must not only speedily perform highly specialized functions (such as IDP) but must also be compatible in size and appearance with other commercial appurtenances among which it will be placed. Because such telegraphic equipment is leased to customers for private use, it is not possible, as in its public telegraph offices, for Western Union to select the area motif and fix space requirements. Equipment designed for such customers' service must embody all the well-appointed features such as noise-level suppression, beauty and comfort, that are so important in our everyday living and the world about us. In short, the oft-quoted "Forward Look" is not to be discounted here in favor of so-called old-line precedent. Many a potentially successful enterprise has ended in disaster because competitive marketability and serviceability were not taken seriously.

Switching System 55-A

Switching System 55-A is a fully automatic switching system designed by engineers of the Western Union Telegraph Company to meet United States Air Force specifications. The system employs standard components of commercial design, components constructed by commercial manufacturers to Western Union specifications, and components manufactured by Western Union shops for use specifically in Plan 55. It was engineered for operating compatibility with message format and operating procedures prescribed by ACP 127 (B) as supplemented by the USAF.

The system employs automatic switching to speed messages through a relay

station at 200 words per minute without attention under normal operating conditions. However, for maximum flexibility, provision is made that any part or all of the traffic load at a station employing this equipment may be manually switched by push buttons.

Telegraph channels derived from either physical wires or radio channels and operated at 60 or 100 wpm can be used for interconnecting relay centers, and for connecting centers with their tributary stations. Each such Plan 55 switching center will accommodate up to 200 circuits and 100 destinations, and has expansion capability to 400 circuits and 200 destinations.

Description

A Plan 55 Switching Center (see Figures 1 and 2) is composed of a group of identical self-contained incoming line consoles interconnected by cable terminated in multiconductor plugs and sockets, and a group of identical self-contained outgoing line consoles similarly interconnected. These two groups of equipment are linked together by cross-office switching circuits over which messages are transmitted at 200 wpm.

Chattanooga Photograph

Figure 1. Main switching aisle looking toward traffic control center. Receiving Cabinets 7502-A on left, Sending Cabinets 7506-A on right, automatic switching director far left

These two basic groups of equipment contain all of the switching means required for manual operation of the relay center. Such facilities provide for push-button operation only. The building block principle thus obtained enables a center to be expanded or contracted as circumstances dictate with a minimum of disturbance to the existing installation. Each console is equipped to provide for the switching of messages to 200 circuits and 100 destinations. Consequently, an installation initially consisting of two incoming and two outgoing circuits may be expanded to accommodate eventually 200 circuits serving 100 destinations merely by adding incoming and outgoing line consoles. The equipment is capable of expanding to 400 circuits serving 200 destinations by the addition of further switching means to the basic consoles. Automatic switching directors are provided which permit all or any part of the switching centers to be operated automatically.

The flexibility of a Plan 55 Switching Center may be further increased by the installation of a traffic control center which permits rerouting cross-office circuits for alternative routing of either high or low precedence traffic, or for diverting traffic for closed stations to storage or refile positions. Additional equipment associated with this center provides supervisory personnel with a visual indication of the current status of any outgoing line sending position. Provision is also made for a visual indication of cross-office positions which may be interconnected at any given moment.

Local supervisory transmitting and receiving positions are provided at strategic points within the station to facilitate the handling of supervisory messages.

Design Requirements

As evidenced in the foregoing description of Switching System 55-A, the require-

ments as set up were rigid and complex. First, possible complete movement of a switching center to a new location made unit structural stability, portability, and self-containment a "must." Second, in the event of a catastrophe to a switching center it was necessary that the undamaged consoles be quickly disconnected from those damaged, then regrouped and restored to service. This requirement, along with the first, made plug and socket interconnections between consoles mandatory. It also dictated that all line conductors in a row of consoles be multipled through a patching panel and out again, thereby providing patching facilities for changing the assignment of any position in any console at will. This feature added to the problem of carrying a large number of conductors (approximately 1500) into and out of each console on a cord and plug basis. Third, reliability of equipment performance must be of the highest order with all wiring and apparatus arranged for easy accessibility and discrete units of equipment made quickly replaceable so that failures in such units may be handled on the "swap-now, fix-later" basis. Fourth, incoming and outgoing line speeds were to be at the rate of 100 wpm maximum and cross-office transmission at a speed of 200 wpm. Fifth, every incoming line console was to be essentially a "master-send" or MX position.

Chattanooga Photograph

Figure 2. Maintenance aisle between Receiving Control Cabinets 7504-A on left and Receiving Cabinets 7502-A on right

Photograph R-10,658

Figure 3. Receiving Cabinet 7502-A (left) open for maintenance. On right, same type cabinet closed for operation

Structural Stability

The first requirement—unit structural stability, portability and self-containment, necessary in the event of a possible relocation of equipment—forced employment of considerable ingenuity. Structural stability and portability went hand in hand. In the case of the line receiving console, (see Figures 1, 2, 3 and 4), the great amount of equipment required to perform adequately all the complex functions of automatic switching made it necessary, for portability, to provide not one large cabinet but two smaller ones. The two cabinets were placed one in front of the other with a walkway or maintenance aisle between the two. Interconnections, front or rear,

were made through an overhead connecting duct.

One front cabinet, designated Receiving Cabinet 7502-A (see Figures 3 and 4), contains all operating and alarm functions and equipment. The 84-inch height of this cabinet, made necessary by the amount of equipment contained therein, influenced the profile. The highest part was sloped forward toward the switching aisle, for accessibility and readability; eye-level portions were placed vertically; below-eye-level apparatus was sloped in reverse to the top section; and apparatus at knee level and below sloped away from the switching aisle.

The rear cabinet was entitled Receiving Control Cabinet 7504-A (see Figure 2) and is exactly that. It contains all of the control equipment necessary to the operating functions and apparatus contained in the front cabinet. All equipment—front and rear—was, of course, designed on a removable basis for maintenance as described later, with all except operations units accessible from the center aisle. Figures 2 and 3 illustrate these points.

Photograph B-10,099

Figure 4. Receiving Cabinet 7502-A—rear view showing accessibility of equipment

Structural stability was attained through the use of square steel tubing in structural welded framework form as opposed to sheet steel construction. As seen in the paragraph above, and in Figure 1, the profile selected was a functional one and somewhat complex. In order that every cabinet constructed be identical to every other one so as to provide good alignment in a row in a switching center, jigs and fixtures were provided. Therefore, five corners of the cabinet profile (see Figure 7) were selected as reference or jig points for which component material was fabricated in advance, using 2-inch diameter round steel tubing.

A jig was designed consisting of two flat steel sides each containing the five reference points in the form of short projecting solid round studs of slightly smaller outside diameter than the five preformed hollow reference corners of the cabinet. Then five hollow tubes were slipped over the projecting studs of the jig, and locked, and all the remaining structural members of the cabinet were welded into place. When completely assembled by welding, the framework was removed from the jig and the remaining parts attached. Such a procedure assured that all the cabinets thus assembled were identical, and no warping occurred due to heat of welding. The complete cabinets, constructed and welded as described above, formed an integral unit, stronger than one of sheet steel construction and approximately 10 percent lighter in weight. Also, since they were jig-constructed, the same reference corners will be used at the time of installation in a switching center to align one cabinet with the next by slipping short rods into these reference corners in one side of a cabinet and then pushing the next one against it and over the rods.

The use of square steel tubing in cabinet construction, where strength and the absence of large, unnecessary flat solid surfaces is desirable, is becoming more prevalent in design today than ever before. The self-containment feature required packaging all the equipment necessary to

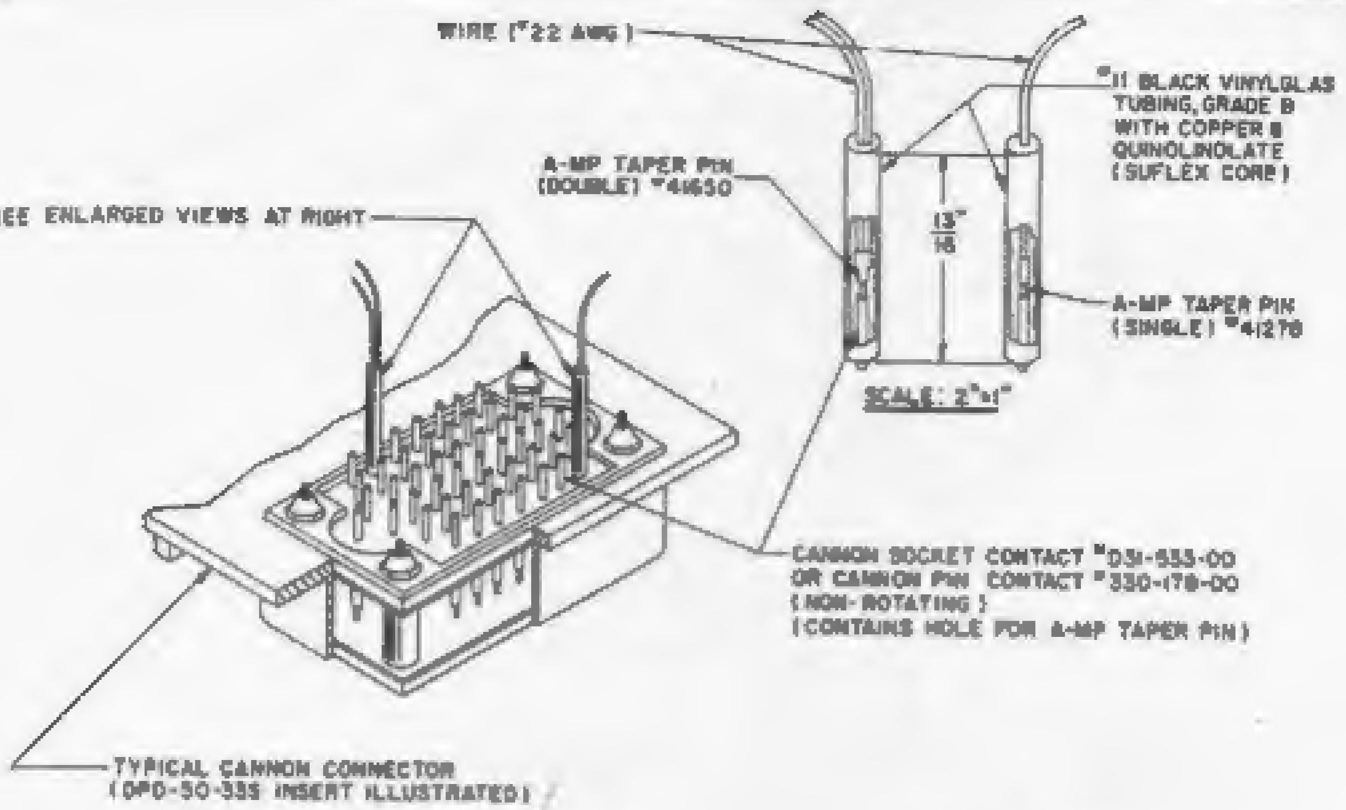


Figure 5. Example of manner of use of connectors and taper pins

the complete operation of each individual cabinet as a part of each cabinet, including a complete and separate source of plus and minus d-c power in the form of mercury vapor rectifiers.

Solderless Connections

The second requirement for easy disconnection (in conjunction with the first) was a factor in the application to this Western Union equipment of the modern solderless technique of wiring. (See Figure 5.) As mentioned previously, approximately 1500 wires had, of necessity, to be multipled into and out of each console. Also, the cabinets had to be quickly removable and portable. This condition, therefore, dictated that all interconnecting wiring between cabinets everywhere in the switching center be on a plug and socket basis (see Figure 6).

The commercial market was scoured for a multiconductor connector which was small and compact and positive in its mating connections and capable of being locked in the connected position. A connector manufactured by the Cannon Electric Company in Los Angeles, California, was found to be satisfactory. It consisted of two identical sides containing a maximum of 78 connections to a side for a total connector capacity of 156 connections, and measured 3-7/8 inches long by 3-3/8 inches wide over-all. Between the two sides of the connector, a locking mechanism manufactured by DZUS and turned by a wing handle was positioned (see Figure 6).

The one remaining problem in the use of this connector was the manner of attaching wires to the male and female portions. Ordinary soldering techniques were found to be too costly and time-consuming in such a small area. It was at this point that the solderless technique of wiring was examined. "Wrap-around" methods were unsuitable in this type of connector, but the taper-pin technique as proposed by Aircraft-Marine Products Company in Harrisburg, Pennsylvania, appeared to be the answer.

The taper pin is a rolled-brass, tin-plated, tapered pin (3-1/2 degrees) which is automatically crimped to the end of each preskinned stranded or solid conductor in a wire form by a specially designed automatic machine (hand crimping tools are also available for field use).

Such a machine is furnished for use with an order of taper pins, and Western Union Chattanooga Works is currently equipped with several such machines. The taper pins

Photograph 8-10,306

Figure 6. Director Cabinet 7514-A, front view, showing cabinet interconnecting cables and connectors

thus crimped to the conductors in a wire form (at the rate of approximately 2000-3000 per hour) are then simply inserted in tapered holes by means of a spring-loaded insertion tool also manufactured by the pin-maker. The same tool may be used for removal of an inserted taper pin.

Since Cannon connectors were normally furnished with solder-pot terminals and not tapered holes for taper pins, Western Union engineers worked closely with the Cannon Electric Company and the Aircraft-Marine Products Company to effect the transition in the Cannon connectors. Such connectors equipped with tapered holes to receive taper pins, in lieu of solder-pots, are now available. Thus it was partially through the efforts of Western Union engineers that such a connector equipped to receive taper pins came into general use.

A second type of solderless connection also employed is the "taper tab" or female counterpart of the taper pin. It is installed on the end of a preskinned wire conductor in identically the same manner as a taper pin. However, instead of being inserted in a tapered hole after crimping, the taper tab is slipped over a tapered lug, which is now available on relays and rotary switches, in lieu of solder lugs.

With both taper pin and taper tab, two crimps take place on the conductor. One crimp provides an electrical connection between the terminal and the bare wire and the second crimp is a mechanical bond on the insulation. This second crimp provides "insulation support" which greatly increases the mechanical strength of the joint. Extensive accelerated corrosion and vibration tests as well as photomicrographs have been run on the taper-pin connections, and extremely good results have been noted. Already, Western Union has gone beyond Plan 55 in the use of taper pins and tapered-hole connectors and it is anticipated that the solderless technique of wiring will replace a large percentage of hitherto soldered joints in future apparatus for which the technique is suitable. In addition to savings in initial labor through the use of the taper pin and taper tab, the maintenance saving is tremendously important. In the past, the removal of a soldered wire from a connector sometimes resulted in burned insulation on adjacent conductors. With the taper pin it is reasonably simple to remove a wire by simply "rocking" the pin gently, thereby loosening it from the tapered hole with resultant easy removal of the conductor.

"Swap-out" Maintenance

The third requirement is one of primary importance to the USAF or any communications center where outage time is intolerable. The first consideration in such a center is to restore service to normal immediately, usually by inserting a spare

unit known to be good, for one suspected to be bad. Little or no trouble-shooting is allowable on a needed working circuit.

The first step in designing to meet this requirement, therefore, was to survey all of the components necessary to each type of console and decide, based on past experience, where failures may occur and to group components into removable, maintainable packages. Reference to Figure 7 will best illustrate this point. Receiving Cabinet 7502-A consists of a basic framework, containing fixed subbases and socket connectors, wired to receive no less than 20 unitized package assemblies. Each such package will have its properly adjusted counterpart stored in a convenient place in a switching center ready for instant substitution when and if needed.

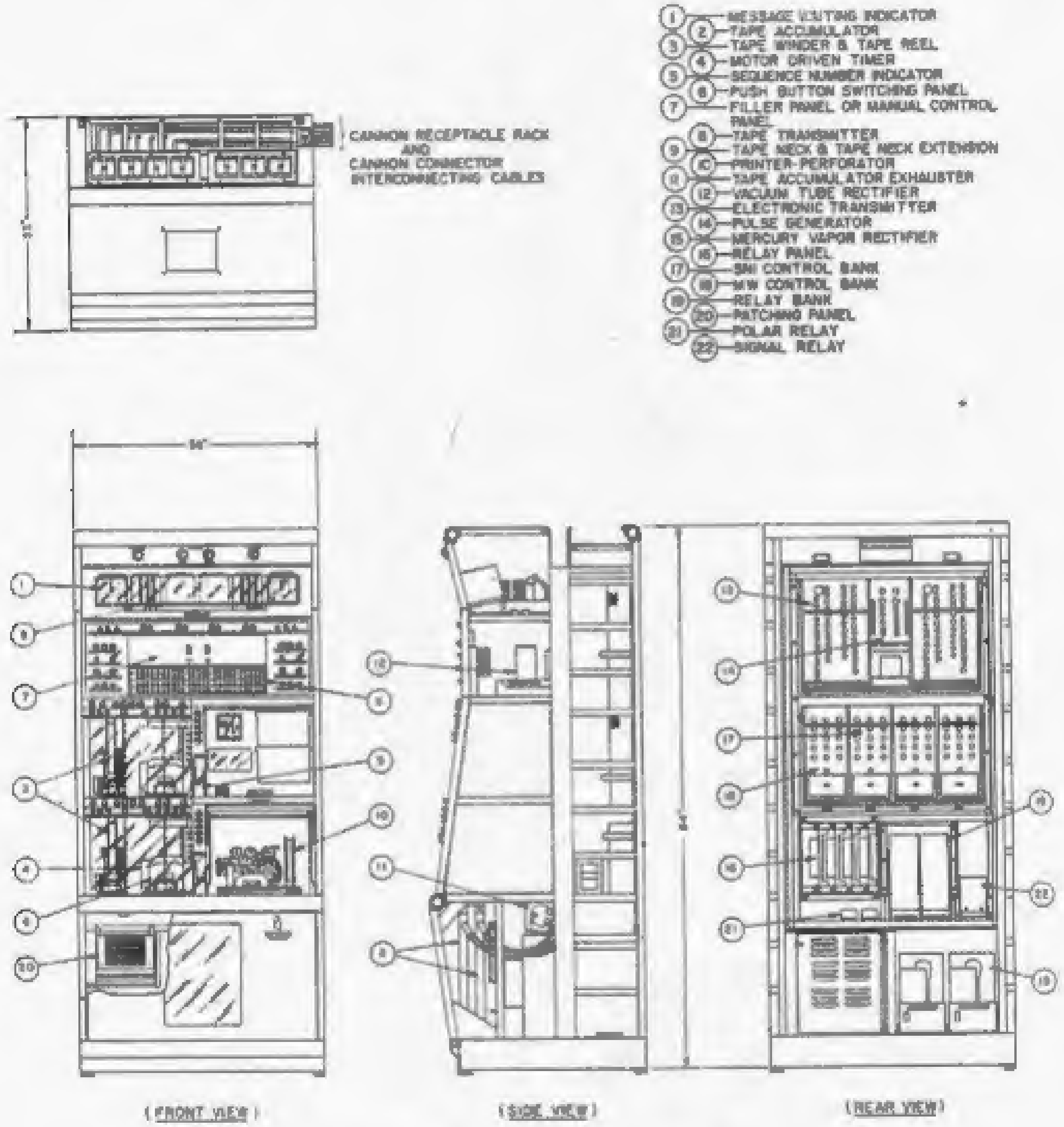
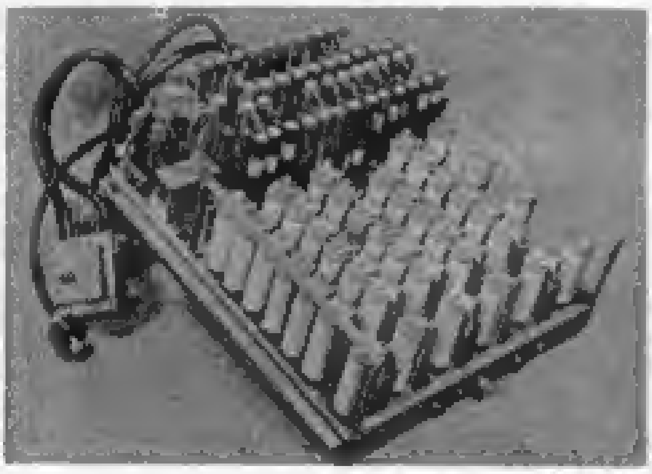


Figure 7. Receiving Cabinet 7502-A—orthographic projection illustrating unitized construction and connector rack atop cabinet

Even though most units are removable and replaceable, an important part of each cabinet design was to build the cabinet in

such a way that as much as possible of its interior and working parts might be opened readily and inspected prior to possible substitution of components. A look at Figures 3 and 4 clearly indicates that virtually all of the component packages become readily exposed in place as required.

Figure 2 shows the maintenance aisle of the incoming line console. The rear cabinets contain all of the control equipment necessary for proper operation of the equipment contained in the front cabinets. Starting from the top and working down, one finds six relay banks, three for the upper incoming line position and three for the lower position; next, two cross-office control chassis (see Figure 8), again, one for the upper position and one for the lower position; similarly, below that two route control chassis; and finally, two route cross-office switch shelves (see Figure 9). All of the units mentioned are

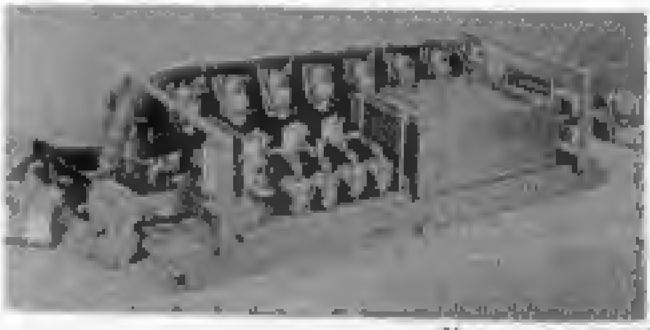


Photograph 8-10,109

Figure 8. Cross-office Control Chassis 7568-A removed, illustrating portability and connectors

removable. All of the units below the banks are provided with drawer slides and may be pulled forward into the maintenance aisle their full length for routine in-place maintenance and inspection. In the case of unknown trouble in the chassis or switch shelves, their connectors may be disconnected from the cabinet wiring, the unit removed and a spare substituted. In the case of the switch shelf, each shelf contains fixed equipment (large rotary switches) for two positions and two removable switch shelf chassis, one of which serves only the upper position and the other the lower position. This illustrates a case where a unit package itself contains a further breakdown of two other removable units. In short, Plan 55 is probably the most flexible unitized system ever introduced by Western Union.

Figure 6 shows Director Cabinet 7514-A which, together with Director Control Cabinet 7516-A, contains the brain which directs the muscles of the switching system. The first consists of a basic metal framework wired to receive seven packaged units of removable apparatus. The entire assembly contains 87,000 feet of wire, 78 Cannon connectors (both male and female), 5100 program jacks, and approximately 2000 semipermanent routing jacks. As a result of careful planning, all of the above equipment is packaged in a single portable cabinet 38 inches wide by 33 inches deep by 84 inches high.



Photograph 8-10,775

Figure 9. Route Cross-office Switch Shelf 7576-A, showing two route cross-office shelf chassis

Finally, each cabinet at the time of installation is simply plugged into an a-c flexipower bus which is either routed throughout the office on overhead hangers or else is attached to the cabinets on brackets at the time of installation. This procedure permits the extension of a-c power throughout the office and to each cabinet on a portable basis, cuts installation time by many hours, and allows removal, and even substitution in a row, of an entire cabinet.

Equipment Test Tables

A necessary adjunct to the "swap-now, fix-later" maintenance program is test and

repair facilities. Figure 10 shows a common test-table group, several of which groups are required in an average size switching center. Complete facilities are furnished thereon for a thorough operational check of each unit of equipment after adjustment and repair.

Line speeds of 100 wpm maximum and cross-office transmission at 200 wpm was the fourth requirement. This meant that the incoming line console be equipped with a 100-wpm printer-perforator and a 200-wpm transmitter capable of reading and interpreting routing indicators and then resending the same routing indicators cross-office along with the body of the message. In the outgoing line console a reperforator was required which would operate at 200 wpm from the cross-office transmitter and a transmitter-distributor which would operate at line speeds of 100 wpm. No such machines were immediately available or had ever been used in Western Union services.

The first step involved a discussion with the Teletype Corporation which resulted in their promise to deliver prototype printer-perforators, reperforators and transmitter-distributors meeting such specifications and in sufficient quantities, to Western Union for testing. Working in close harmony with Western Union engineers, Teletype engineers modified their new Type 28 line apparatus to perform in the required manner in Plan 55 switching equipment. The end result of these efforts was a 100-wpm printer perforator Type 28-LPR, a 200-wpm reperforator Type 28-LRPE, and a 100-wpm transmitter-distributor Type 28-LBXD.

Chattanooga Photograph

Figure 10. Test Tables 7652-A and 7634-A and Equipment Rack 7672-A

Loop-Gate Transmitter

The next equipment problem was to obtain a 200-wpm transmitter capable of reading routing indicators at the beginning of a message (in tape form), and at the same time holding the beginning of the message in such a way that after the routing indicators had been read, the beginning of the tape could be returned to the transmitter pins and the whole message transmitted cross-office including the routing indicators previously read. To accomplish this, Western Union engineers developed Loop-Gate Transmitter 7595-A which has a sliding gate over the read pins. After reading and checking the incoming message number, the sliding gate moves to the left and allows the routing indicators only in the tape to build up in a vertical loop over the transmitter (see Figure 3, upper transmitter position). When the last routing indicator has been read, the gate slides back to the right and places the first routing indicator back in position over the transmitter pins. It reads routing indicators and transmits cross-office at 200 wpm. This transmitter is already being used in patrons' switching centers other than Plan 55 and shows excellent possibilities of coming into more general use.

With the advent of increased transmis-

sion speed, the old problem of tape movement from the reperforator (200 wpm) and printer-perforator (100 wpm) into the accumulator and out again into the transmitter-distributor and transmitter, respectively, through a tape neck, became considerably aggravated. The situation was particularly bad on upper positions where the distance traveled by the tape is considerably longer than that traveled from the lower position. In previous systems operating at 65-75 wpm, suction was applied to the tape accumulator and tape neck by means of a tape accumulator exhauster. This served to keep the tape fluttering in the tape neck and aided in its downward travel. It also served to keep the downgoing tape from snagging the upgoing tape during operation, thereby preventing tape jams. Because of the increased speed in Plan 55, this method proved unsuccessful.

In Plan 55 another problem in addition to speed entered the picture. The Type 28 machines pressed or pierced a row of feed holes into the tape rather than punched them as in the Type 39 and other equipment. This condition also served to aggravate difficulties in the tape movement down and up the neck, to and from the accumulator. Radium salt static eliminators, long in use in switching systems, were also used to aid in the tape movement, but accomplished little in preventing tape jams in the neck itself.

Tape Stiffener

For several years, company engineers had entertained the thought of using a device, attached to the printer-perforator and reperforator, to crimp the tape on its two edges along its entire length as it left the machine, thereby stiffening it in preparation for its downward travel through the tape neck. This would act much the same as a flange on a thin piece of sheet metal. This idea was carried out in model form some time ago,[1] but in all cases the standard machines lacked the necessary power to accomplish the crimping operation and still feed tape satisfactorily.

A short time ago, one of the engineers hit upon the idea of a tape device mounted in place of the common tape neck and containing a set of motor-driven tape creasing rollers. The rollers travel at a slightly greater speed than the printer-perforator or reperforator feeding tape into it, and are driven through a slip-clutch. Therefore, instead of the perforating machine having to push tape through the creasing device, the creasing device itself actually *pulls* the tape through the creasing rollers using its own source of power. The device so developed is known as Tape Crimper 8432-A and contains features such as tight-tape cutoff and tape tie-up indicator switches.

All tests carried out thus far indicate its worth. There is little chance of a tape jam within the tape neck due to snags of the downgoing and upcoming tape as occurs with limp, uncreased tape. The same size tape accumulators now will hold approximately 20 percent more tape than heretofore, because the tape now packs itself so much tighter. The rather expensive tape accumulator exhauster and radium static eliminator are no longer required.

Electronic Transmission

As stated previously, cross-office transmission in Plan 55 is at the rate of 200 wpm. It was not mentioned, however, that this cross-office transmission takes place over one wire per cross-office circuit rather than ten as in Plan 21. This, then, is "electronic" cross-office transmission at 200 wpm.

To accomplish this, a stable source of d-c power was designed for both the incoming line console and the outgoing console. This source of power is in addition to the larger mercury-vapor rectifiers in each console and is known in each case as a vacuum tube rectifier. The power supply is used to operate an electronic transmitter and pulse generator in the receiving cabinet and an electronic receiver and pulse generator in the sending cabinet. Other such units in Receiving Cabinet 7502-A are message waiting control banks and sequence number indicator control banks.

The type of design of the electronic units

Warren H. Fisher was graduated from Stevens Institute of Technology in May 1943 with the degree of Mechanical Engineer. Immediately thereafter he joined the Bethlehem Steel Company in Sparrows Point, Maryland, where he served three years in the capacities of Estimates Engineer, Test Engineer and Assistant Chief Test Engineer in the Ship Building Division. In 1946 he joined The Western Union Telegraph Company and served as engineer successively in the departments of the Central Office Engineer, the Apparatus Engineer, the Specifications Engineer and the Patron Systems Engineer. His work has been on the design of such projects as Plan [illegible], Plan 31, the Baltimore Telecar Program, Facsimile, and Plan 51, 53 and 54. In early 1954 Mr. Fisher was made Project Engineer under the Patron Systems Engineer and assigned to the engineering of Plan 55 in charge of Mechanical Design.

is new to Western Union practice and an interesting one. The units, exclusive of the rectifiers, are built on a flat 1/4-inch thick aluminum chassis plate with a rolled hook at the top. The vacuum tubes are all mounted perpendicularly on the front of the plate and all the components (resistors, capacitors and diodes) are mounted between soldering terminals staked to bakelite panels which are mounted perpendicularly to the rear of the chassis plate. Complete air circulation is thus allowed over, under and between all tubes and components, when the units are mounted in the cabinet shown in Figure 7. The units are hung on a bar by means of the rolled hook at the top of the chassis and the chassis is rotated downward to a vertical position in the cabinet. A female connector mounted behind the chassis plate engages a male connector, attached to the rack, as the chassis is rotated downward to the vertical position. Thus, it is a simple procedure to remove an electronic package and insert a new one—merely a matter of seconds.

The fifth requirement resulted in another phase of the solderless technique. A row of incoming line consoles and a row of outgoing line consoles was not to exceed 15 cabinets in length. This meant that in the case of the incoming line console, with two positions per cabinet a total of 60 line conductors or 30 pairs of wires would be required to pass through a patching panel in each cabinet. Added to this, all alarm conductors and optional feature conductors were also to pass through the same patching panel. The total number of jacks required in the incoming line console was determined to be 390 and in the case of the outgoing line console, the patching panel required 1300 jacks. The greater number of jacks in the outgoing line console was required because nearly all cabinet interconnections were of necessity passed through the patching panel instead of just the line conductors and alarm functions.

To build such patching panels using telephone type jacks was out of the question in view of the enormous proportions such a panel would assume. Here again, the Aircraft-Marine Products Company presented the logical solution. The company has marketed a jack-block molded of nylon, and containing 20 double-ended single-conductor jacks of the size to fit the A-MP taper pin. Such a block is only

4 inches long by 5/8 inch wide by 5/16 inch high and is made in such a manner that it will nest with another, thereby employing the building block principle. In Figure 7, Item 20 illustrates the size of the 390-jack patching panel relative to the size of the receiving cabinet. All the required cabinet conductors are terminated in the jacks behind the patching panel. The front of the patching panel is then ready to receive patches using patching cords made of 22-gauge stranded instrument wire, of the desired color, which have been tipped on each end with a taper pin. The cord, colored to denote certain functions or locations, may easily be inserted and removed by means of the insertion tool. Such a patch cord has the added advantage of being practically vibration-proof and unaffected by changes in temperature and humidity. It occupies very little space and its simple construction makes storage of large quantities of patch cords unnecessary.

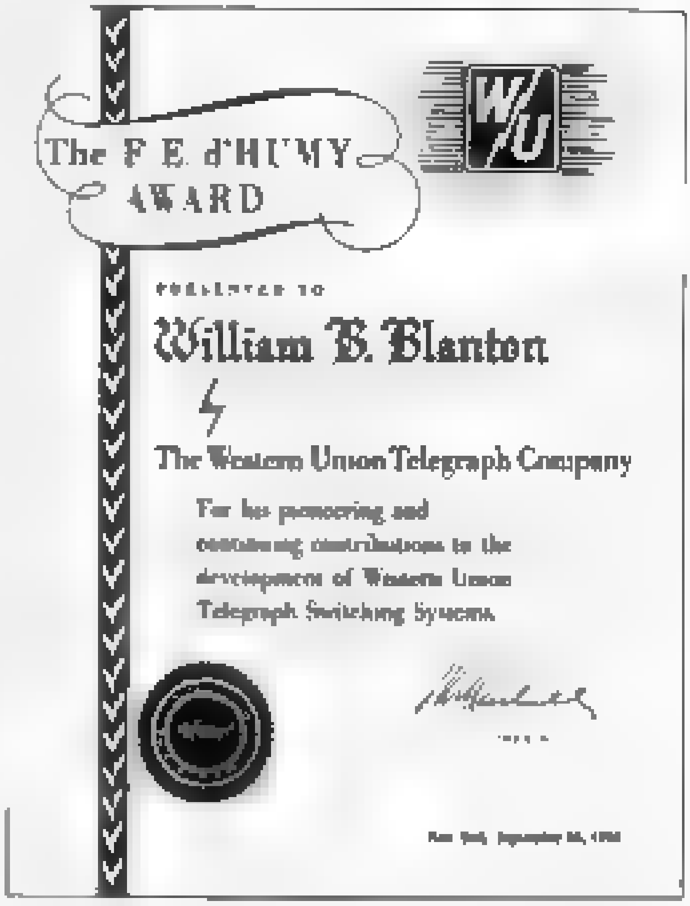
Conclusion

The foregoing article illustrates some of the many and varied strides which are currently being made in Western Union engineering. Plan 55 was selected as the most suitable object of discussion since many new ideas and techniques have been introduced in the design of the equipment for this system.

While the system described represents the latest trends in engineering techniques, proper consideration has been given to economy. Intelligent over-all economy is a fundamental requirement in any engineering design. The proper selection of the building material, careful consideration to design of the component or structure to give the greatest ease of construction in the shops, familiarity with the latest developments in methods and materials, and an ability to recognize and specify the commercial parts representing the greatest value for the dollar, all play a highly important part. Adherence to these general rules of economy is extremely important in any program, but particularly so in one of such a scope as Plan 55.

Western Union is meeting the demands of the public-at-large, the business world in general, and the armed forces in particular with advanced technology in communications. A salute to "Telegraphic Communications 1956"!

Award Certificate



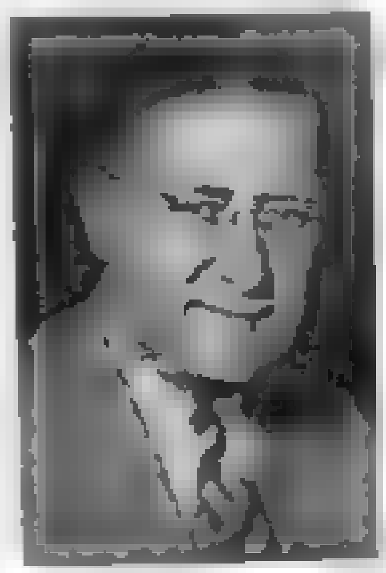
Certificate of the F. E. d'Humy Award for 1956 recently presented with medal and honorarium

Reference

1. Perforated Tape Cleaning Device, F. J. HAUPT, *Western Union Technical Review*, Vol. 7, No. 2, April 1953.

William B. Blanton Awarded 1956 d'Humy Medal

William B. Blanton, an expert in telegraph switching design and application techniques, has received the Telegraph Company's F. E. d'Humy Memorial Award for 1956. Presentation of the three-inch French bronze medallion and the citation certificate, accompanied by a check for $500, was made by Western Union President Walter P. Marshall at a special ceremony at Sixty Hudson Street, New York, on September 28, at the conclusion of a technical symposium on "Business Automation."



WILLIAM B. BLANTON

The d'Humy Medal was established by The Western Union Telegraph Company in recognition and commemoration of the achievements of the late Fernand E. d'Humy, Vice President and Director of the company, whose inspired leadership and able guidance in telegraph research and engineering laid a firm foundation for the company's technical achievement.

The award to Mr. Blanton was made "for his pioneering and continuing contributions to the development of Western Union Telegraph Switching Systems" on which he has been engaged for 34 years. In his current assignment as Automation Engineer in the Development and Research Department he is responsible for much of the telegraph company's rapid technical progress in the field of automatic message transmission.

A graduate of Virginia Polytechnic Institute, Mr. Blanton joined the equipment engineering division of Western Union in 1922. From that time, he has been continuously employed in the development and engineering of circuits and equipment for manual, semi-automatic and automatic switching systems that handle telegraphic communications by printer, reperforator and facsimile methods. From both a supervisory and detailed design standpoint, he has taken an active part in the development of reperforator switching from the first trial installation at Ft. Worth in 1934 until the completion of the nationwide reperforator switching network described in his article in the Technical Review of January 1952 and in previous articles. On becoming Switching Development Engineer in 1949 he took charge of all new switching systems used in the company's services and leased to private industry and the Armed Forces. He was appointed to his present position in 1955.

At the technical symposium preceding the award presentation, papers were presented on "Control System for Integrated Data Processing," by Philip R. Easterlin, on "Fully Automatic Telegraph Switching System," by Charles J. Holloman, and on "Self-Checking Codes for Data Transmission," by George O. Vincent, all of Western Union.

ALBERT BOGGS, Assistant to Radio-Wire Transmission Engineer

Computers, Analog and Digital

With an understanding of basic mathematical background, it is possible, as a rule, either to arrange a problem to fit the computer or to choose a computer—analog or digital—most suitable for the problem. A discussion of the possible application of analog and digital methods to problems in electrical network theory brings this subject into the field of telegraphy.

When some new and significant development in technological progress comes to the attention of an individual with an average amount of scientific curiosity, his reaction is likely to be that he would like to know how it works, but failing in this he will be well enough satisfied if he can master enough of the new vocabulary to tell some one else how it works.

This discussion of computing machines is therefore not an attempt to explain how they work but only to explore some of the implications of the descriptive terms "digital" and "analog."

Computation would ordinarily be thought to imply some operation involving the use of numbers and if this be so all computing machines are digital computers if for "numbers" we substitute "digits," the basic components of all numbers. However, if finding the answer by any means whatever may be called computation then the door is opened to admit processes that are not strictly numerical. As an example, suppose a tank has the dimensions 6 inches by 10 inches by 30.8 inches and it is required to find the cubical capacity of this tank in gallons. A digital computer would multiply the numbers 6, 10 and 30.8 together and divide the product by 231 and find the quotient to be the number 8. The operator must supply the additional information that the capacity is eight gallons.

Another type of computer might make use of a pint measure and count the number of pints required to fill the tank. In this case the number will be 64. At this point a digital computer could be used to divide 64 by 8 and reach the answer 8 gallons. Observe that the liquid used is immaterial and that with the dimensions given a quart or a gallon measure would have given as accurate results but had the height been 31.3 instead of 30.8 inches the pint would be much preferred.

This in a crude fashion is illustrative of that general process wherein measurement is substituted for calculation. The measurements need not be and most often are not applied to the system or device in question but to some other which can be handled more conveniently and which is so constructed that the results obtained with this analog system represent accurately the original system when properly interpreted.

Suppose the problem were presented to determine that rectangular figure enclosing the maximum area A that can be constructed with a fixed perimeter S and we wish to use an analog computer to solve this problem. A preliminary step in the use of any computer, analog or digital, is to state the problem in a form compatible with the operational principles of the computer. Alternatively, it may be necessary to choose a computer whose method of operation fits best with the form in which the problem must be stated. In the present problem we will assume the second condition to hold and state the problem which the computer must solve in a manner which we believe to be the preferred form.

To do this, call one side of the rectangular figure X and the other Y. Then

$$Y = \frac{S}{2} - X$$

and

$$A = XY = \frac{SX}{2} - X^2$$

Since this is a problem of "maximum value" we write the dependence of A on X as

$$\frac{dA}{dX} = \frac{S}{2} - 2X$$

and the problem is solved if a value of X can be found which will make the derivative $\frac{dA}{dX}$ = zero It is this part of the problem we ask the computer to solve

We choose an electronic device containing differentiating circuits in which voltage will be the analog of length To make the design of the computer easier, the constant quantity S will be called unity and the differentiating circuits will be constant current devices, i.e., the current will be proportional to the applied voltage or at least very nearly so.

With $S = 1$ the expression for A becomes,

$$A = \frac{X}{2} - X^2$$

A block diagram of the computer is shown in Figure 1. E is a source of a saw-tooth voltage function with E varying from zero

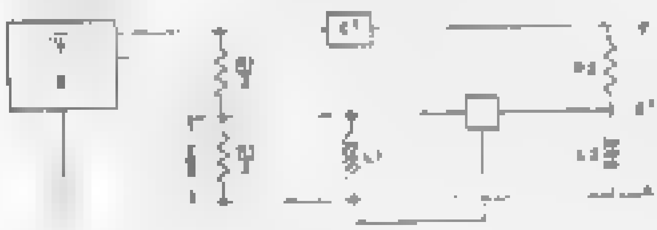


Figure 1. Block diagram of a computer

$R1 \gg L1$
$R2 \gg L2$
$L1 = L2$

to unity. $E/2$ is applied to inductor L_1 through a high-resistance voltage divider R_1. A voltage

$$L_1 \frac{dI}{dt} = \frac{L_1}{2} \frac{dE}{dt}$$

is developed across L_1. The full voltage E is applied to a voltage squaring device and the squared voltage delivered to the series $R_2 - L_2$ circuit. A voltage

$$L_2 \frac{dI}{dt} = L_2 \frac{d(E)^2}{dt}$$

is developed across L_2 A relay connected across L_1 and L_2 detects the instant of time when these voltages are equal and stops the generator at this point The value of E at this moment is read on the generator voltmeter If the full scale meter reading is 10 and the generator stops at 2.5 the value of X relative to S is 1/4, which would mean that maximum rectangular area for a fixed value of perimeter will be realized if the rectangle is square

If a saw-tooth generator and a voltage squaring device should prove troublesome to make these difficulties could be avoided by using a sinusoidal voltage $E \sin Bt$ E will be the analog of S and $E \sin Bt$ the analog of X

If S is made equal to unity the expression for A is

$$A = \frac{1}{2} [\sin Bt] - [\sin^2 Bt]$$

and

$$\frac{dA}{dt} = \frac{B}{2} \cos Bt \, [1 - 4 \sin Bt]$$

If $\frac{dA}{dt} = 0$, $\sin Bt = 1/4$ and
$X = S/4$

This avoids the saw-tooth waveform and the squared value of voltage can be avoided by writing

$\sin^2 Bt = \frac{1}{2} [1 - \cos 2 Bt]$ which indicates that for a squaring device a frequency doubler and 90-degree phase shifter is substituted. The need for a phase shifter may be eliminated by letting $X = E \cos Bt$, since

$\cos^2 Bt = \frac{1}{2} [1 + \cos 2 Bt]$ The d-c term occurring in these double angle equivalents need not be provided in the doubled frequency voltage supply since it will contribute nothing to the derivative.

These examples of analog computers may at first sight appear to be rather trivial. A more critical analysis would probably lead to the same conclusion. However, it is believed that some basic principles are established The maximum area problem is essentially one requiring that derivatives be evaluated so an electrical analog circuit capable of per-

forming that operation was chosen. With this choice made it was then advantageous to express the defining equation in a form leading to easily realized analog quantities.

A simple problem that would be susceptible to solution by means of a digital computer will now be considered.

Given $X^2 - 12X + 20 = 0$

Find the roots, i.e., the values of X which will satisfy the equation.

If we had to solve this problem without the aid of a digital computer we would factor the original equation and obtain

$$(X - 2)(X - 10) \quad 0$$

and then reason that if either factor were zero the product would be zero and so identify values of X either $+2$ or $+10$ as being those values which satisfy the equation.

The computer cannot reason but can only perform the digital operations of addition, subtraction, multiplication, and division. We must therefore set up some program involving only these operations and instruct the computer regarding which of these operations shall be performed and in what order

As a first step we will enter the numerical coefficients of the original equation

1	—12	20

and instruct the machine to square each of these coefficients obtaining

1	144	400

Then instruct the machine to subtract from each squared coefficient twice the product of the original coefficients lying equidistant on either side and so obtain

1	144	400
0	—40	0
1	104	400

Now tell the machine to continue this process, squaring the remainders and subtracting the doubled products until no significant difference occurs when the subtraction is made. The results obtained in carrying out four such successive operations are:

n	1	—12	20
n^2	1	144	400
	0	—40	0
r^2	1	104	400
n^4	1	10816	160000
	0	—800	0
r^4	1	10016	160000
n^8	1	100320256	25600000000
	0	—320000	0
r^8	1	100000256	25600000000
n^{16}	1	10000051200064536	65536×10^{16}
	0	—51200000000	0
r^{16}	1	10000000000064536	65536×10^{16}

The last subtraction produced changes only in the 7th significant figure and beyond.

The machine will stop here and display the results as they occur in the last line. It has not been told what to do next but at this point the operator may as well take over, knowing that the middle column is now the 16th power of the largest root and that the last column is the 16th power of the product of the largest root and the next to largest root. Sufficient accuracy will be obtained if the last five digits are assumed to be zero and the first root written as

$$(r_1)^{16} = 10000000000000000$$
$$= 10^{16}$$
$$r_1 = 10$$
$$(r_1 r_2)^{16} = 65{,}536 \times 10^{16}$$
$$r_2 = 2$$

This example is intended to demonstrate at least three features characteristic of digital computers:

A program of digital operations within the capabilities of the machine and which when carried out will give the right answer must be set up by the operator.

The machine must be capable of handling numbers consisting of large quantities of digits.

The accuracy of the results obtained will depend upon the digit capacity of the machine and also upon the stage in the program at which calculations are stopped.

Observe that if proceedings had been interrupted at the r^4 stage, and the roots determined from the contents of the 2nd and 3rd columns at this point, the values found for r_1 and r_2 would have been

$$r_1 = 10.04$$
$$r_2 = 1.992$$

This shows that computer time may be conserved if demand for extreme accuracy is restrained

A type of problem that might be solved by either an analog or a digital computer can be illustrated by the proper fraction

$$\frac{f(X)}{F(X)} = \frac{X^2 + aX + b}{X^3 + cX^2 + dX + e}$$

An algebraic expression of this form can represent the performance of almost any physical system.

For solutions for various values of X by either method the fraction in a factored form is desired. Take for example the fraction

$$\frac{X^2 - 12X + 20}{X^3 - 8X^2 + 19X - 12} = \frac{(X-10)(X-2)}{(X-4)(X-3)(X-1)}$$

The digital computer can accomplish the factored form by finding the numerator and denominator roots, using the procedure outlined above, and then perform the indicated operations of subtraction, multiplication, and ultimately division for any selected value of X. For a value $X = 12$ the solution would be:

$$\frac{f(X)}{F(X)} = \frac{(12-10)(12-2)}{(12-4)(12-3)(12-1)} = .07575$$

The values of X which make the numerator zero, the numerator roots, are usually called zeros and the denominator roots are called poles. In this example the zeros are +10 and +2 and the poles +4, +3, and +1

The analog method will make use of these poles and zeros also but in a quite different manner. As a first step $\frac{f(X)}{F(X)}$ will be expressed in terms of natural logarithms.

$$Ln \frac{f(X)}{F(X)} = Ln\,(12-10) + Ln\,(12-2)$$
$$- Ln\,(12-4) - Ln\,(12-3)$$
$$- Ln\,(12-1)$$

This solution consists of the logarithms of the differences between the roots and the value of X selected.

The X's and r's are only numbers and can represent the magnitudes of any physical quantities we wish. Let them represent lengths. Then any X-r is the distance between X and r. If we decide to deal with measurable lengths, we have entered the field of analog computers and will next try to identify some familiar physical quantity which has the form

$$Y = Ln\,(X - r)$$

This is recognized as the potential at point X in a plane produced by a line charge of unit charge per unit length perpendicular to the plane at point r. Since potentials are additive the total potential at a point X is the sum of the potentials produced at X by the line charges at each of the r points. The logarithmic solution contains plus and minus signs and for this reason both positive and negative charges will be used in the analog. It is customary to represent poles as + and zeros as −. There may be some question whether or not this will lead to the correct polarity for the potential, or correct algebraic sign for the answer, but who among us can always be sure to connect voltmeter leads correctly at the first try?

A plot of the pole-zero pattern is shown in Figure 2

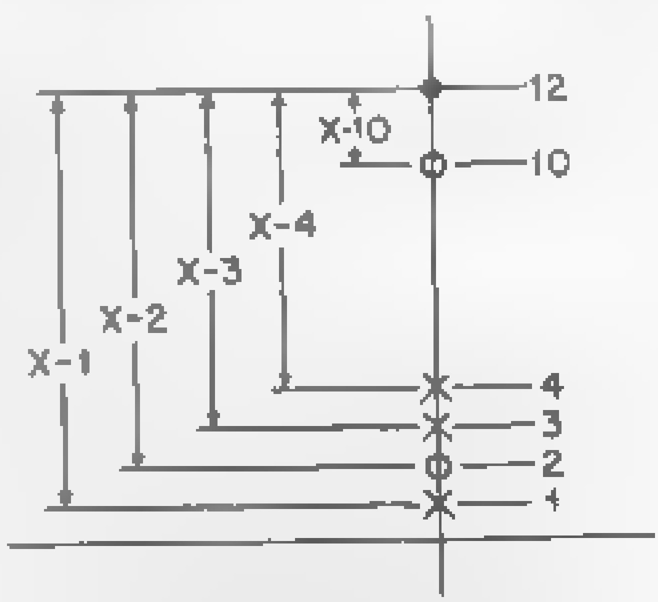


Figure 2. Plot of unit charge distribution representing poles (X) and zeros (O) of

$$\frac{(X-10)(X-2)}{(X-4)(X-3)(X-1)}$$

Assuming now that such an array of charges can be set up and that potentials can be measured, the solution of the original equation for any value of X can be found by determining the potential at the position X.

The function of X chosen for this example had only real roots which perforce were plotted in the real X axis. Had the roots been imaginary they would have been put on the horizontal axis and, if complex, somewhere in the plane of the figure but not on either axis.

If this device is used for calculation of the performance of electrical networks containing reactive elements, complex roots will quite likely occur.

In our discussion of this analog method mention of potential theory and functions of a complex variable has been avoided, but what has been said here may serve to put the reader in the position of that Moliere character who was delighted to discover that he had been using prose all his life but didn't know it. Knowledge of how any of these computers actually work was disavowed at the beginning but an inclination to elaborate a bit on the potential analog method may have been observed.

The method is basically simple except for the difficulty encountered in setting up line charges and in measuring potential in space, otherwise there are no problems. Fortunately both these difficulties can be circumvented by using constant currents introduced at pole and zero points in a conducting medium and measuring voltage at points along a line chosen as the real axis. If authentic sources are consulted some confusion may arise concerning where the real axis really is. This is only because electrical network theory constitutes the major material dealt with and the idea of a complex frequency as the independent variable is a convenient conception. This is to say $Ee^{j\omega t}$ is preferred to $E = \cos \omega t$ in the solution of a-c problems. When this transformation is made, a further simplifying complication is introduced by assuming that E might really be complex and, since impedances containing reactive elements always are, using an arbitrary character "p", tacitly complex, throughout. Thus the current in a series R-L circuit with applied voltage $E \cos \omega t$ is

$$I = \frac{E\,e^{pt}}{R+Lp} = \frac{E}{L} \cdot \frac{e^{pt}}{p+R/L}$$

The denominator has one root, $-R/L$, which is real for the current expression written in this form, and the logarithm of the current is,

$$\begin{aligned} Ln\, I &= Ln\,\frac{E}{L} - Ln\,(p + R/L) \\ &= Ln\, E/L - Ln\, Z\,(p) \end{aligned}$$

Variation of current with frequency ω is usually the question of major interest and ω seems to have disappeared. Remember, however, that for convenience all quantities that ordinarily are functions of ω were transformed to functions of p and the reverse transformation can be made whenever we feel the need. This simple transformation, in either direction, is only a 90-degree rotation of coordinate axes and a plot of either function can be made on the same diagram with the real and imaginary axis labels interchanged.

The solution of this a-c problem in graphical form is shown in Figure 3 for $L = 1$, $R/L = 4$, $\omega = 3$.

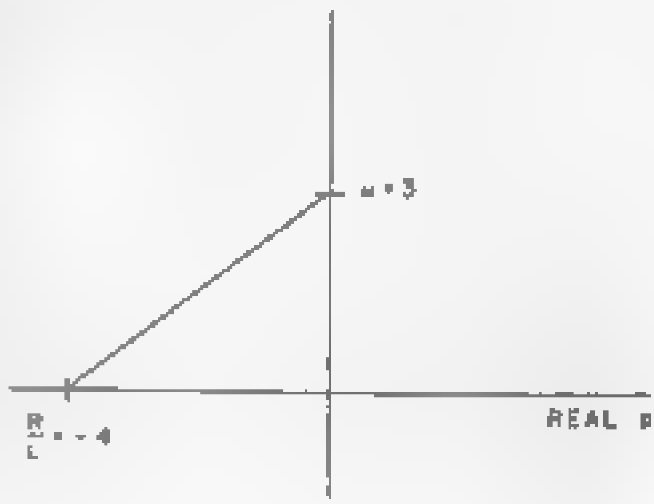


Figure 3. Plot of impedance $Z = L\,(p + \frac{R}{L})$

It was mentioned earlier that the potential at any point in a conducting medium surrounding a current source is a logarithmic function of the distance from the source. Then if a current of one ampere

were introduced at the pole position $p = -4$, the voltage at the point $\omega = 3$ would be the logarithm of Z after suitable calibrations for conductivity and units of length are made. This is about as simple an illustration as can be contrived and being simple makes the potential analog method appear unnecessarily cumbersome, but all problems are not so elementary and this combination current and voltage analog process is finding wide application in many fields of research not confined to analysis of electrical networks.

In a paper written by W. W. Hansen and O. C. Lundstrom and published in the PROCEEDINGS of the IRE, August 1945, the use of an electrolytic tank as the conducting medium was described. In recent years a considerable number of research organizations have been using the dry conducting "Teledeltos"* paper developed by Western Union for facsimile recording as a very satisfactory replacement for the electrolytic tank.

Perhaps enough has been said to delineate in a general way the kind of problems suited to the two types of computers and to indicate the techniques used. However it must be admitted that the fields of application are by no means clearly differentiated. I have on my desk literature describing an improved analog computer, the improvement being the use of digital computation for enhanced accuracy.

*"Teledeltos"-Trade Mark Reg.

Albert Boggs, Assistant to the Radio-Wire Transmission Engineer, majored in physics at Ohio State University, graduating in 1925. Following a year there as Graduate Assistant in Physics he received the Master of Science degree and then joined the Research Division of Western Union. His activities have included mathematical studies of various phases of signal transmission, investigation of inductive interference and development and application of mitigative equipment, development and application of carrier loading and impedance matching systems, correction of distortion and related problems. Mr. Boggs heads the group which is responsible for development of inductors, transformers and electric networks and which has designed the numerous types of filters widely utilized in Western Union carrier systems. He is a member of Phi Beta Kappa and Pi Mu Epsilon, honorary mathematics fraternity. For a number of years, Mr. Boggs has been Adjunct Professor of Electrical Engineering at the Polytechnic Institute of Brooklyn, teaching courses in network theory.

J. H. TOOP, Canadian National Railways

Operation of Electronic Brain Computers With Telegraph Circuits

Designed for actuation by five-unit perforated tape, the FERUT electronic computer at University of Toronto has been used successfully for solution of problems transmitted 1700 miles over Canadian telegraph circuits. A description of this computer and the manner in which it was associated with conventional telegraph operation follows an informative introduction on computers in general and the binary number system. Although duplicate transmissions provided an accuracy check for the Saskatoon-Toronto programmes, it seems unlikely that method would be favored in regular practice.

Recent developments whereby leased teleprinter circuits are used to carry mathematical problems to "electronic brain" computers, and return the answers, point the way to future advances in the use of leased circuits for telemetering. Electronic Data Processing (EDP), automation, scientific research, and other applications requiring distant installations to be connected to central automatic control points for the exchange of information and instructions.

The evening of December 15, 1955, saw the first tests successfully completed at the University of Saskatchewan in Saskatoon when mathematical problems programmed into computer code were transmitted in this code on a teleprinter circuit for some 1700 miles to the FERUT computer at the University of Toronto. Here the programmes were received on a nonprinting reperforator ready for input into the computer. After computation, the answers were "transcoded" by the computer at Toronto and sent in Baudot code on the same circuit to Saskatoon, where they were printed on a page printer, ready for immediate use.

Calculating Machines in History

Man has probably used some kind or another of mechanical aid as long as he has been calculating. These primitive aids gradually became standardized and rules for their use were formulated. An early example is the calculus of the Thracians; dark or white pebbles (calculi) were used to count dark and happy days. A further refinement in handling numbers was the abacus whose counters (pebbles or beads) are pushed along lines or wires to tally counting. The abacus is still widely used in Asiatic countries, often with telling efficiency.

The industrial revolution stimulated attempts to mechanize mathematics. The most notable of these were the Difference Engine and Analytical Engine by Charles Babbage, a professor of mathematics at Cambridge who was greatly impressed by the punched card system used to control the pattern on the newly-invented Jaquard Loom. He adopted that system for his computing "engines" and designed both machines in full detail. Unfortunately for posterity lack of funds kept the Difference Engine unfinished, and prevented even a start on the Analytical Engine.

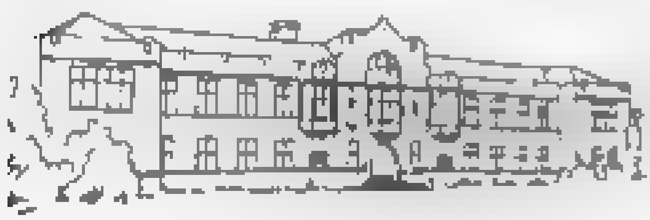
The Difference Engine was to compute tables (such as logarithms and trigonometric functions) by adding differences. The Analytical Engine was designed as a general purpose computer and foreshadowed modern computer practice in many of its operating principles. There were two parts—the "store" which held numbers to be operated upon and received the results, and the "mill" where the actual operations were carried out. Thus two sets of cards were used, one set for the numbers and the other to direct the operations.

Babbage also foresaw that in the course of some computations logarithms or trigonometric functions would be required. The engine, he said, could either refer to

tables in the form of more punched cards, or compute the desired values as it went along. Interestingly enough this latter problem has not yet been settled either way in modern computers. Some, like ENIAC, use tables, while others like FERUT compute the functions desired.

Modern Calculating Machines

In the century following Babbage's work (the early 1800's) advances in computers were limited to minor refinements of relatively simple computational aids but this situation began to change when the science of electronics came into its own in the period between the two world wars.



Courtesy Canadian National Railways

University of Saskatchewan

The last war saw many small computers built into specialized equipment for rather restricted applications. Examples of these were in gun ranging, rocket control, aircraft location, and coordinated controls within aircraft. Since then the use of computers has advanced to the point where their manufacture has become a minor industry. As an adjunct to automation, computers will soon be a commonplace piece of business and factory equipment.

Basically there are two types of computers, "analogue" and "digital," or "mathematical instruments" and "calculating machines" as they are known in Europe. The analogue computer, as the name implies, *computes by interpreting physical measurements made on a model.* The slide rule and planimeter are well-known examples where numbers are represented by lengths and areas. Electrical models are widely used to study flow problems, since the laws governing electrical, liquid, gaseous, or heat flows are very similar, and also to study motion. Analogue computers have the advantage of being able to handle continually changing quantities,

"All concepts of processing information are due to grow rapidly with the development of computing machines, and their usability will be greatly expanded by private wire circuits . . . ." Professor W. H. Watson, University of Toronto.

a process akin to integrating in the calculus. However, they are limited in accuracy both by the accuracy of the model used and by the accuracy of the instruments used to make the measurements.

In contrast, *digital computers deal with the numbers themselves,* usually by counting discrete events, from beads on a wire to electrical impulses in a circuit. While they cannot handle integration problems they can solve the equivalent summation or infinite series. Their accuracy is unlimited, so the operator need only specify in advance the number of significant figures required in the answer, be it three or thirty.

The FERUT Computer

The FERUT computer at Toronto may be taken as a representative example of a digital computer. Like other computers it is named, the FER from the builder's name (Ferranti Ltd., Manchester) and UT for the University of Toronto, where it is located. The computer cost $500,000 and was provided by the Defense Research Board of Canada.

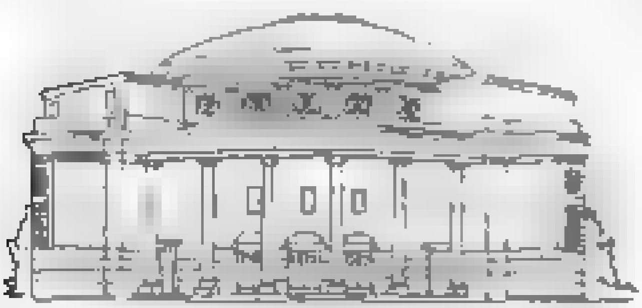
Following the principles foreshadowed by Babbage, this computer consists of two parts. *The magnetic store,* which corresponds to Babbage's store, holds the numbers to be operated upon during the calculation, the instructions directing the operations to be performed with the numbers, and the results of the calculations. *The electronic store* corresponding to Babbage's mill, carries out the actual operation of calculation.

Eight cathode ray tubes mounted on the control console make up the electronic store. They may be considered as eight pages on which the mathematician records his operations and their results, and are therefore called "pages." Each page has room for 1280 binary digits (abbreviated "bits") in 64 lines of 20 bits each, which are arranged in two vertical columns of 32 lines each.

The magnetic store consists of rotating drums plated with a magnetic substance. Each drum has 256 tracks, each track having a capacity of two pages of information. Thus one page of electronic store space makes one "half track" of magnetic drum storage space. Each track has a head associated with it for writing information into the drum storage and reading it out.

Writing information into the drum storage, or reading it out, is known as magnetic transfer. "Writing transfers" are from tube to drum and are referred to as "up" for simplicity. "Reading transfers" are from drum to tube, or "down." Transfers are made in blocks of one or two full pages; part pages cannot be handled. Transfers are made at the full working speed of the machine since each drum is kept rotating in exact synchronism with the 100-kc fundamental rhythm of the machine.

The computer then may be visualized as a desk on which eight pages are available for computation, and having cupboards above, each holding up to 512 pages of indexed information. A "down" transfer means taking one or two pages from the cupboard and copying them on pages on the desk, and returning the originals to the cupboard. An "up" transfer is like copying one or two pages from the desk and putting them in the cupboard, and throwing away the pages that were in that section of the cupboard.



Courtesy Canadian National Railways

Convocation Hall—University of Toronto

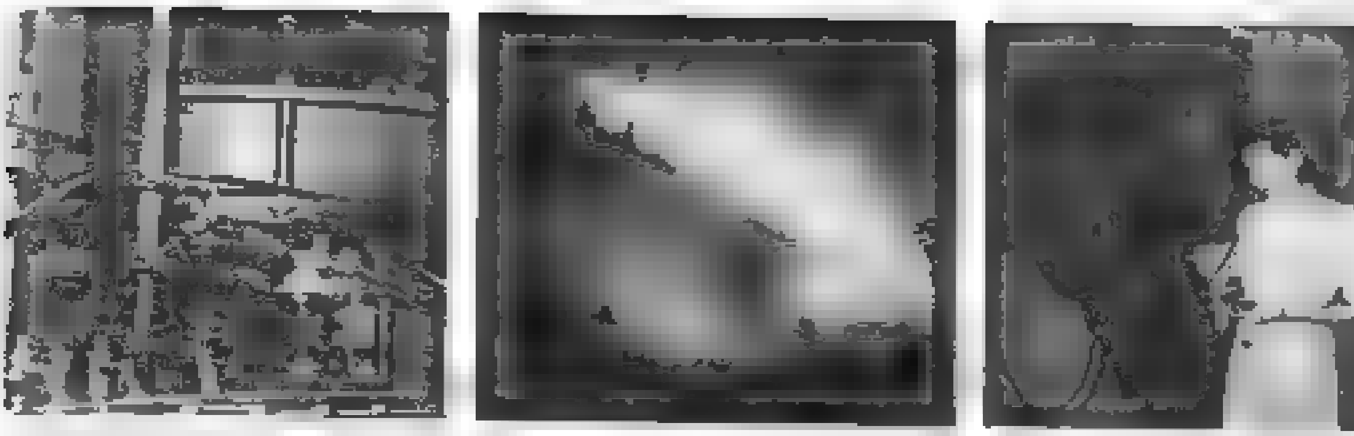
Binary Number System

The FERUT computer uses a binary number system for its computations, rather than the decimal system of ten digits which is employed in everyday notations. In the decimal system the values of the digits from right to left are units, tens, hundreds, thousands, and so on in powers of ten. In the binary system the values of the digits from right to left are units, twos, fours, eights, sixteens, and so on in powers of two. Thus 11001 means $16+8+0+0+1=25$. The binary number system has only the two digits 0 and 1. Two is then written 1 0, three 1 1, four 1 0 0, and so on. The number system thus has a "base" of 2. The last digit of the number means the value of the digit (0 or 1) is multiplied by 2^0 or 1, the second last digit has its value multiplied by 2^1 or 2, the third last digit has its value multiplied by 2^2 or 4, the fourth last digit has its value multiplied by 2^3 or 8, and so on. This is exactly what is done in the decimal system, except that here the "base" is 10, the last digit has its value multiplied by 10^0 or 1, the second last has its value multiplied by 10^1 or 10, the third last by 10^2 or 100, and so on.

This explanation may help the unfamiliar reader over the first hurdle of binary digits. They are not difficult once one realizes that the "numbers" that are represented do not change, it is the way they are written down and figured with that is changed.

At first glance this may seem an awkward system to work with, but it has proven very suitable for computer work because the two digits of the binary system can be so easily represented in electric or magnetic ways, such as (+) and (−), N and S, current or no current, charge or no charge, and so forth. Also, mathematical operations can be carried on with the greatest of ease with the binary number system. If one were to try to choose one digit from ten possible digits by this method, he would have to have ten positions of which only one carries a significant marking to identify one digit. This method also involves some difficulties in computing. For example, 11001 in binary digits means $16+8+1=25$, and is written in a space of five binary digits, each of which is significant. By contrast the number 25 would require 20 units of space in the decimal system, of which only the "2" and "5" digits are marked.

In the FERUT computer the binary digits of a number are written in the reverse order to the usual notation. That is, they are written with the ascending powers of the base 2 going to the right.



Problems transmitted by wire for FERUT solution included those of nuclear physics studies, aurora interference investigations and cancer research at U of Saskatchewan. Shown here are part of Betatron 25-million volt electron accelerator (left), "ray arc" aurora detector, and cobalt "bomb" for cancer treatment (right)

Thus the number 25 is written 10011 as used by the computer but as 11001 written on paper. This is a distinct advantage for the mechanical operation of the computer, since any number of zeros following the number does not alter its value.

Five bits can be combined to form a "character" (abbreviated ch). These characters have the same signal codes as the Baudot code. However, the 32 FERUT characters may actually be used as the 32 digits of a number system to a base of 32.

Floating Decimals

Another interesting point about the numbers used in the FERUT computer is the form in which they are handled, in input and output. All numbers use "floating decimals." That is to say, every number is written as a value between 1 and 10, using enough decimals to give the required accuracy. A (+) or (−) following shows if the number is to be positive or negative. Another number followed by a (+) or (−), behind the first number, shows the power of ten to be used as a multiplier to give the actual magnitude of the number. For instance

$$3.71356+\ 3+ = +3.71356 \times 10^{+3} = +3.71356 \times 1000 = +3713.56$$
$$8.0031-\ 2- = -8.0031 \times 10^{-2} = -8.0031 \times 0.01 = -0.080031$$
$$2.1331-\ 1+ = -2.1331 \times 10^{+1} = -2.1331 \times 10 = -21.331$$

and so on. These are the "standard forms" of numbers as used in much scientific work.

Although the computer uses binary digits in its operation, the numerical material is programmed into the machine in decimal form. This may seem contradictory but it simplifies the programming.

Programming

Once the numbers that are to be used in the computation have been arranged in order, the proper sequence of operations must be arranged so the computation will be carried out in the right order and the answers stored until needed. Arranging the numbers and the instructions and preparing them in the coded tape is known as "programming," and a problem prepared and ready for input into the computer is know as a "programme." Thus the "programme" consists of two parts, the first part containing the "constants" which are all the numbers with which the computations begin; the second part is the "instructions" which give the detailed sequence of operations to be carried out with the constants.

The position of a number on a page in the store is known as its "address," and is specified by page, line, and column. The address is used to identify the number in the subsequent instructions. So a part of the instructions (translated) might read. "take the number in column two of row

five of page one, multiply it by the number in column one of row seventeen of page two and record the result in column one, row one, of page five and then subtract this result from the number in column one, row eight, page two. Take the result . . ." and so on.

It can thus be seen why programming is the most important aspect of computer operation. Not only must the programmer set up the problem so the proper operations will be carried out to achieve the desired result, but he must understand the operation of the computer so he can organize the programme to keep expensive computing time to a minimum, make the fullest use of the machine's potentialities, and avoid pitfalls which would cause the machine to snarl the operation.

It must be borne in mind that the computer will only blindly follow the instructions given to it, and cannot discern any inconsistencies in the method. For instance, some machines working on the function $\frac{3}{x-2}$ will continue to work on the problem indefinitely when $x=2$ and the denominator is zero, while a human mathematician would never try to divide by zero. In this case, the programmer gave the instruction "divide by $x-2$" but did not add "except when $x-2 = 0$."

FERUT and other recent scientific computers will stop and question the problem when they come to a division by zero, but this is used simply as an illustration of the meticulous care required to avoid mathematical inconsistencies.

Industrial Computers and Scientific Computers

This division of the programme into "constants" and "instructions" has one very important result. Once a problem of a given type has been programmed, it can be repeated for any new set of data by simply programming the new constants and repeating the previous instructions. This adds immensely to the flexibility of the computer in doing routine calculations.

This is also how the computer evaluates logarithms, trigonometric functions and other functions for use in the course of the computation. The instructions for computing the function are first placed in the store in pages whose locations have previously been agreed upon. These instructions are then referred to in the proper place in the problem and the result is applied to the computation as required. As fast as FERUT can scan data, it can compute the values faster. This method also ensures that the function will be found to the correct degree of accuracy as required by the problem. A rather unique kind of "library" at the FERUT computer has the instruction tapes for a large number of these functions and standardized problems. The qualifications required for a librarian in this library are probably the highest of any in the world.

This ability of the computer to repeat type problems brings out the fundamental difference between computers used mainly for scientific purposes and computers used for routine industrial work like EDP. Computers used for scientific work may be fed a dozen problems in a day, each problem unique and unrelated to any of the others. Each problem is programmed according to its own specific requirements. However, a computer doing industrial work may handle hundreds or thousands of routine calculations of one type before the instructions are changed for the next batch of data.

As a result, computers in scientific work have a comparatively modest "memory" for constants but must be designed to carry on very involved calculations with the material used. Computers in industrial work must have a prodigious memory for the vast amount of data to be processed, but generally perform only a few relatively simple operations with this data. Very often the instructions are not even fed into the computer as such, but are either built into the machine, or introduced as a switchboard controlling the circuit connections. Often a machine is provided with several interchangeable switchboards wired for the respective operations that it is used for.

Long Distance Solutions

As soon as FERUT was installed and working, problems began to come in from outside the University of Toronto. The computer staff then analyzed the problem, programmed it, fed the programme into the computer, and returned the answer with the bill

Students from other universities came to the computer to do post-graduate work and get a good working knowledge of the machine and its operation. One of these was Bob Bruce, an Edmonton student taking his Ph.D at the University of Saskatchewan. On his return from Toronto he gave a series of lectures on the computer to interested staff and student members of the mathematics and science departments of the University of Saskatchewan

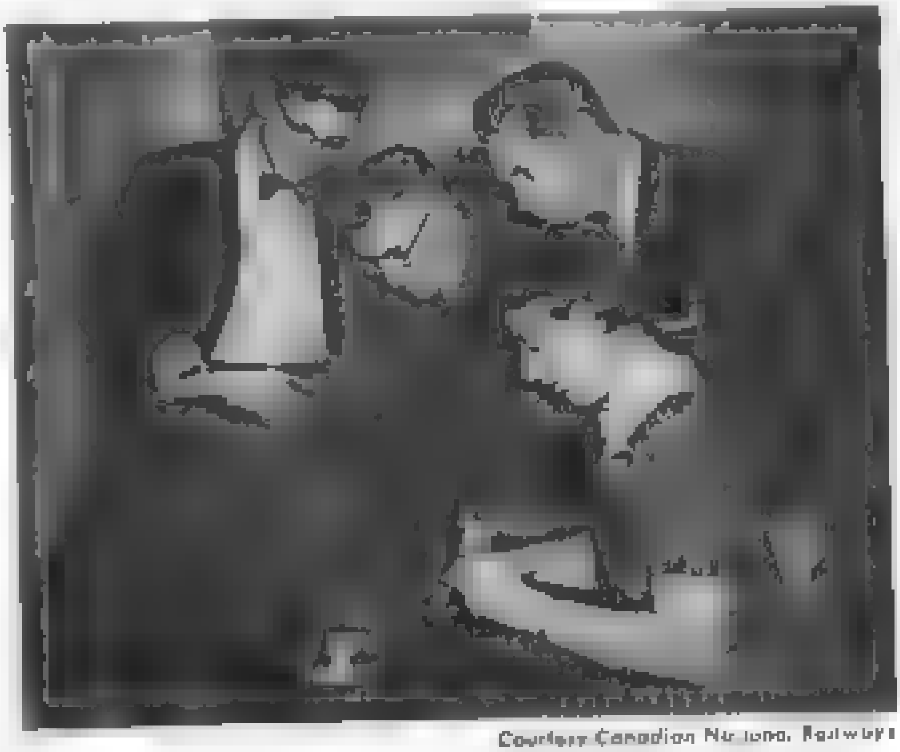
It was found that a great many mathematical problems arising in different fields of research could be profitably solved by computer methods These mathematical problems are often a bottleneck in fundamental research since their solution can take much longer than the actual experimental work

Fortunately FERUT is designed to input programmes from standard teleprinter tape although as was said before, the code designations are not those of the Baudot code. Accordingly a tape perforator was borrowed and some problems were programmed at Saskatoon and the tape mailed to Toronto for solution This saved the programming step at Toronto and had the added advantage that the person with the problem did his own programming

Logically the next step would be to use a teleprinter circuit to send the programme to Toronto and return the answers. This procedure was planned by Dr. W. H Watson, Head of the Department of Physics, and Dr C. C. Gotlieb, in charge of FERUT, both at the University of Toronto, and by Dr. B. W Currie, Head of the Department of Physics, and Bob Bruce, both at the University of Saskatchewan. Late in the fall of 1955 the two universities arranged the tests with the Canadian National Telegraphs, and the necessary equipment and circuits were made available

The Tests

The first test was held on Thursday, December 15, 1955 Contact between the two universities was established on schedule at 8 P.M. EST, 6 P.M MST A preliminary check showed circuits and machines all ready and functioning



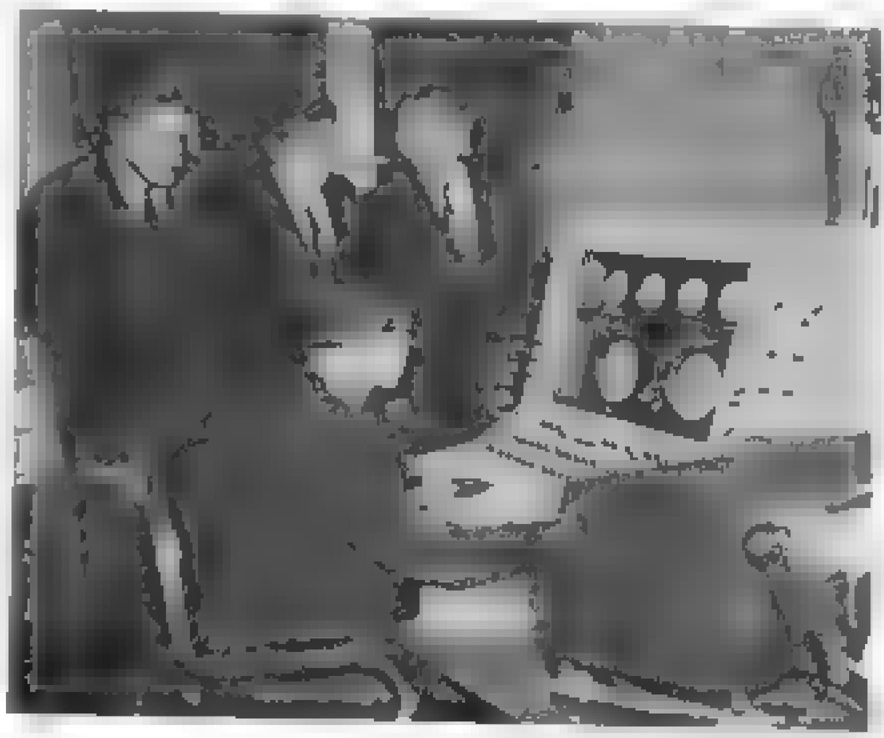
Courtesy Canadian National Railways

Programme material for FERUT computer is perforated in tape at University of Toronto

Calculations for ten research problems were programmed for the first evening's tests. Three were problems in nuclear physics arising out of Drs. L. Katz and R. N H Haslam's research with the betatron, the 25,000,000 electron-volt accelerator at the University of Saskatchewan. One problem by Dr Johns was to analyse animal husbandry statistics using matrices (a mathematical method) The other six problems originated in research on northern lights under Dr Hunten

Programme tapes were sent from an automatic transmitter in Saskatoon and copied on a nonprinting reperforator in Toronto. The tape as received at Toronto was all ready for input to the computer. This intermediate tape at Toronto was necessary for two reasons. First, each programme was sent twice so that the two tapes could be checked in Toronto to see that no transient errors had crept into the tape during transmission. The slightest garble would alter the programme and so ruin the computation. Second, a 60-wpm circuit was used, that is 360 characters per minute. But FERUT inputs at 200 characters per second, or 12,000 characters per minute, which is equivalent to 2,000 wpm. Hence there was no possibility of inputting direct from the circuit.

A test programme is run through the computer before beginning a series of calculations. This is a short problem designed to test all the computer operations and see that they are functioning correctly. The answer is known so any errors show that the computer is in trouble and give an idea of where the trouble lies. On the first evening this test tape was sent from Saskatoon, and the answer transmitted back for checking. Following the test programme, the prepared programmes were sent.



Courtesy Canadian National Railways

Prof. W. H. Watson, U. of T. (left); K. D. Jenner, CNT private wire services; D. H. Hawley, CNT chief of commercial operations, and Dr. C. C. Gotlieb, U. of T. (seated) watch FERUT computer control console

The time saved in computer work can be appreciated from the first night's work. The computer solved problems in 20 minutes to an hour and a half that would have taken a mathematician six weeks to four months to do with a desk calculator. The whole evening's computations would have taken one man about a year, and some of the problems would not otherwise have been attempted.

Circuits Used

The circuit assigned for the test was a regular leased teleprinter circuit set up for 60-wpm operation. A single circuit is used with operation in both directions. The merits and demerits of a full duplex circuit set up in a round-robin arrangement with customer switching at each end have been considered. This did not seem to offer any advantages over the present arrangement, but it is being kept in mind in case it should prove suitable for other applications.

The present circuit is used only on occasional evenings by prior arrangement between the universities. When an evening's test is planned, the wire chiefs are advised and the connection established. The rest of the time the drops to the universities are terminated in the wire chief's office. This allows the drops to be used as "local" circuits or office circuits at each end, which is suitable for preparing or reperforating programmes.

Equipment Requirements

Since FERUT's input, except for speed, and output are fully compatible with standard teleprinter equipment, no important modifications were necessary for

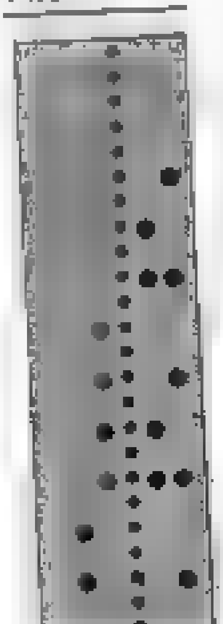
the tests. As mentioned before, FERUT inputs from perforated teleprinter tape at 200 characters per second (2,000 wpm). Output may be on a page printer at 6⅔ characters per second (66⅔ wpm) or on a perforator at 15 characters per second (150 wpm), or on both at once. Usually this output is "transcoded" from the binary system into decimal number notation and outputted in Baudot code, so the tape is ready for transmission to the circuit without any further processing. The word "usually" is employed because occasionally the results are required in binary numbers. Thus a Model 19 Teletype and a nonprinting reperforator were all the teleprinter equipment required at the computer end at Toronto. Any further equipment was already available.

A similar set of equipment was also found adequate at Saskatoon. The tape punch previously mentioned was retained for convenience. The keys of the punch were "modified" by placing adhesive tape over the ten keys representing the ten decimal digits in FERUT code. The key designation in Baudot code and the FERUT digit were then inked on the tape and this was suitable for test purposes. The Baudot code corresponding to the keys which were changed, the decimal digit represented and the number in binary notation are as follows:

It must be remembered that the programme tape must be letter-perfect before inputting to the computer because the slightest error changes the computation. Furthermore, FERUT code does not permit errors to be corrected in the tape by striking over the LTRS perforations as can be done with the Baudot code. Naturally it has been found difficult to prepare programme tapes up to 30 yards in length without some errors, and the correction of errors became a problem.

The first answer to the error problem was to cut out the faulty "page" in the programme and splice in a perfect page in its place. However the splice had a tendency to introduce spurious signals in passing through the automatic transmitter. The nonprinting reperforator solved this problem. The programme was taped, then checked for errors. A faulty page would be retaped on a separate piece of tape. The programme was then sent through the automatic transmitter as far as the first faulty page. Then the transmitter was stopped, the perfect page substituted and sent, and finally the balance of the perfect programme sent. Meanwhile a continuous tape was prepared on the reperforator. This new tape was then compared with the original and if found correct, used as the master tape for the regular transmission. A duplicate master tape could be cut from this master tape in the same manner if so desired. The reperforator was also handy to copy the results from Toronto.

BAUDOT CODE



Key	Digit	Binary Notation
Blank	0	00000
E	1	10000
Linefeed	2	01000
A	3	11000
Space	4	00100
S	5	10100
I	6	01100
U	7	11100
CAR RET	8	00010
D	9	10010

The tape could then be used to print additional copies of the results when the loop was on local.

A selector system could be added to the circuit if a large number of offices were working with one computer. This would allow one or more offices to work with the computer without disturbing the machines installed at the other offices.

General Transmission Problems

The basic difference between analogue computers and digital computers must be kept in mind when discussing the problem of transmitting instructions and results to and from these computers. Analogue computers work from a physical model and handle continuously changing quantities, but are limited by the accuracy of the measuring device. Digital computers work with numbers, are not limited in accuracy, but there must be a small but finite interval between each number.

Except for very short distances, readings cannot be carried in the form required for analogue computers with any degree of accuracy. This is because the physical measurements transmitted are liable to distortion in the transmitting medium. Distorted writing on the Telautograph machine shows the effect of transmission over a distance. Changed tone and quality in voice-frequency circuits is another example of how difficult it is to keep a physical quantity constant over long transmission lines.

The solution is to translate the physical readings into numerical values which are then transmitted at intervals. This is what is done when a voice channel is put on an AM carrier circuit over long distances. The carrier waves are modified in height by the voice wave. Each carrier cycle is modified to a height (number) according to the voice wave at that time, and this information is sent at intervals corresponding to the carrier frequency. Thus when analogue information is transmitted as a sequence of readings (or numbers) the problem has become identical with transmitting digital information in a sequence of digits.

So in either case one number or reading (or a cycle of a carrier wave) is sent at a time. Another cannot be sent before the first is finished, so they must follow each other at appropriate intervals. This is fine for transmitting digital information since this is its natural form, but analogue information must be translated back into a continuous form at the receiving end. As is known from experience with carrier phones, this method does not ensure perfect reproduction of the original signals; there is always a slight distortion due to lag. This problem of transmitting analogue information with accuracy will likely be more important in telemetering service than in computer service or Integrated Data Processing.

"Transcode" Problems

A desirable goal in any transmission of data for IDP is to use the Baudot code and standard teleprinter equipment whenever possible. Failing this, it may become necessary to employ special equipment and circuits or make provision for dual-purpose circuits handling both kinds of signals.

Computer practice, like Topsy, has "just growed" and many methods and codes are used for input and output. Fortunately FERUT was designed to be compatible with Baudot code, but not all other computers are so conveniently arranged. Punched cards are popular for computers used in industrial work, but even here there are variations. Some mechanical translators are now available to repunch information from one type of card to another, and I.B.M. has card-to-tape and tape-to-card translators to punch card information into Baudot code and vice versa.

It is likely that industrial computer equipment will become more standardized in codes and handling methods, and that the transmission problem for IDP will thereby be simplified. Computers used in scientific work will conform to industrial practice in general, but will differ in detail as designers pioneer new methods and improve on old ones. The scientific com-

J. H. Toop received his Public School education at Madison, Sask., and completed high school at Parkside, Sask. at which points his father was station agent for the Canadian National Railways. In 1941 he was employed by CNR as spare Agent-Operator, subsequently worked numerous positions on the Saskatchewan District, and in 1946 was appointed to the agency at Hughton, Sask. which position he held until 1952; for eight years of this period he also worked intermittently as Relief Agent on the Saskatoon Division. Late in 1952 he transferred to early night hours at the Lorne Avenue Block Office in Saskatoon Terminals where shortly thereafter the first exclusive Railway Department teleprinter on the Saskatchewan District was put into service. For the past three years he has worked the evening shift while studying at the University of Saskatchewan. At the May 11, 1956 Convocation the University granted Mr. Toop the degree of Bachelor of Arts (Cum Laude). He wishes to continue his studies in mathematics and physics having future computer work in view.

puters will require special treatment or modifications to equipment and circuits.

The communications companies must prepare for the problem that will come with greater use of leased circuits for IDP. Two solutions are possible; one, to translate or "transcode" all data to Baudot code for transmission, the other, to arrange circuits to handle the data in the code in question. In the latter case there will probably be a demand for dual-purpose circuits, handling plain language material in Baudot code with conventional teleprinter equipment, and data for processing in another code with the necessary equipment. Customer switching would be most suitable for this service.

Less commonly used computer codes might require an extra step of transcode to bring them into a code for which a card-to-tape translator was available. This method is inconvenient and increases costs, besides increasing the chance of errors through the additional processing. It will not be popular with customers and should encourage manufacturers of the equipment to provide card-to-tape and tape-to-card machines as a part of their product line.

On the other hand, transmitting the data in the code used will simplify the customer's problem but raises the same difficulty for the communications company. Monitor and test equipment suited to the various codes will be necessary, and some switching questions may arise in dual-purpose circuits. As with any new development, many problems will require solution, but that of transcoding will probably never be entirely eliminated.

Conclusion

The tests on which this article is based have shown that the perfect transmission accuracy required for computer problems can be achieved using conventional equipment and circuits. Duplicate transmissions were found to solve the accuracy problem in this case but the fact is not overlooked that other kinds of checks are possible and may be more suitable for other applications. It was seldom necessary to transmit more than twice to confirm any programme to Toronto. It might be emphasized here that the duplicate transmissions were made consecutively in these tests because of the kind of circuit used. However, it is felt that transmissions should be consecutive even when more circuits are available, since simultaneous transmission on two circuits would subject both transmissions to possible simultaneous garbles since both circuits would be carried on the same pole line or cable for part of the route at least.

Present leased circuits are adequate for plain language transmission since most garbles can be corrected at the receiving end without repeating the material. This is much more difficult for IDP material, and the chance of undetected errors is therefore much greater. A device to detect and register garbles due to hits and other momentary circuit interruptions would be very valuable on these circuits. An alarm in the customer's office would show when a garble had occurred and the garbled section of data could then be repeated.

These and other similar tests now in progress indicate the trend of future communications requirements for telemetering and IDP as these become the backbone of nationwide automation. It is probable that circuits leased for these services or for dual-purpose purposes will become more numerous than those now used for teleprinter leases, just as the latter have eclipsed individual telegrams as the bulk of telegraphic communications.

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INSTRUCTIONS IN PROGRAMMING OF THE MANCHESTER ELECTRONIC DIGITAL COMPUTER. DR. D. G. PRINZ, Ph.D.

FERUT [illegible] OF THE TORONTO COMPUTER AND THE REMOTE PROGRAMMING OF [illegible] *Computers and Automation*, Vol. 5, No. 5, May [illegible]

George O. Vincent entered Western Union as a messenger in Salisbury, Md., in 1931 while continuing in school. After training as a teleprinter operator he filled assignments in various offices until 1934 when he was trained in teleprinter maintenance at Bloomfield School where he also later instructed. He has worked as a maintainer and a teleprinter maintenance supervisor and was manager at Bel Air, Md., Sayre, Pa., Westfield, Rutherford and Passaic, N. J. From 1945 to 1950 he was in the General Office on the staff of the Superintendent of Tariffs, where he was instrumental in the design of tariff listings and rate sheets for the company's new rate structure. In 1951 he returned to the Eastern Division as Division Supervisory Assistant, Private Wire Services, where he handled the U. S. Air Force Plan 51 network account, Intrafax and PWS sales assignments. Since 1954 Mr. Vincent has been in headquarters Private Wire Services and at present is in charge of the administrative group in the office of the Assistant Vice President—Facsimile and Private Wire Services.

Photograph P-9729

GEORGE O. VINCENT General PWS Supervisor, Facsimile and Private Wire Services

Private Wire Switching System Plan 54

The first practical postwar push-button telegraph center for private wire service was Western Union's Plan 50 system similar to the improved Plan 51 system described in TECHNICAL REVIEW in 1948. Improvement of this 60-button-panel switching system was so rapid that Plan 52 with automatic switching, and Plan 53 featuring automatic transmission through the first relay office without reperforation, never left the laboratories. The 125-push-button Plan 54 systems, as described below, with over twice the capacity of Plan 51, have been in service for some years. Elimination of sending circuit cabinets and cabling has greatly simplified installation with Plan 54.

An ultramodern, high-speed, continuous tape push-button switching system, designed by Western Union engineers for customers with medium and large volumes of communications, is designated Plan 54. This system is now in service for many private wire networks customers in the United States and it is used by an air line in Canada.

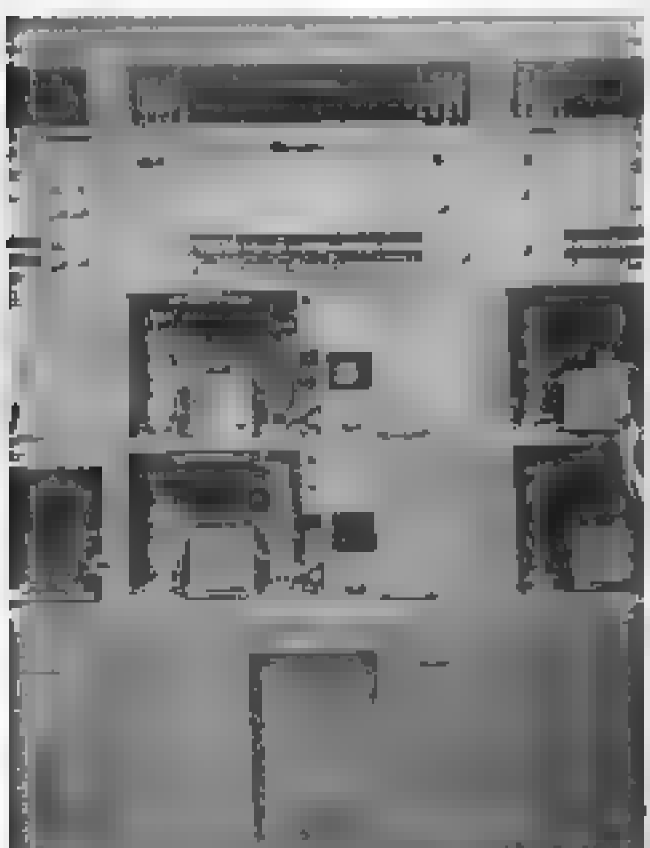
At one or more switching centers messages arrive from network stations on printed, perforated tape. The attendant at a center determines the destination, simply pushes the appropriate button and the message speeds onward automatically. The push-button method of switching provides direct control and supervision of operations.

The Plan 54 Switching System is compatible with most other types of Western Union switching systems and can usually be installed as added centers on existing

systems of other types with no change in fundamental operating procedures. The various units making up a Plan 54 Switching Center and its features will be described individually.

Reperforator switching cabinet, Figure 1, is the "heart" of the Plan 54 Switching System. The smartly styled cabinet has been designed to provide the utmost in operating convenience for the attendant, with push buttons and controls arranged to permit easy and natural movements. Even such details as the normal contours of an operator's clothing have been considered in the design of this unit.

The necessary cabinets are usually installed in two rows facing each other, with a "switching aisle" between them. The cabinets are double-decked, providing upper and lower receiving positions; a push-button turret is common to both positions. Each receiving position contains facilities and space for one printer-perforator and an automatic transmitter. To accommodate any pause in transmission, there is a tape accumulator which stores the unsent tape loop between the printer-perforator and the transmitter. The accumulator box is partly evacuated of air by a vacuum pump to assist in moving the tape down.

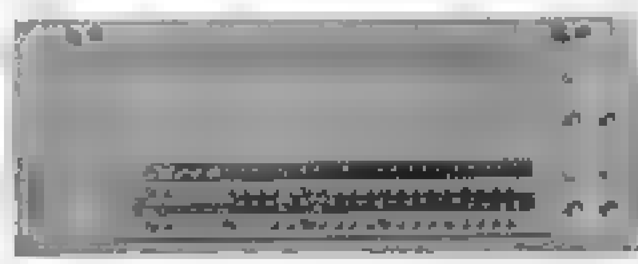


Photograph 8-10,149

Figure 1. Reperforator switching cabinet is principal component of Plan 54 system

The push-button turret, Figure 2, is made up of five separate strips, each with 25 push buttons and neon lamps, or a total capacity of 125 units. Each sending circuit, including cross-office, local circuits, and so forth, is assigned one push button, labeled to indicate the station it serves. An additional button is needed for each station on selectorized way circuits, unless "preselection" (insertion by originating stations of destination selection functions) is used.

Switching is accomplished by noting the destination on the tape; depressing a button at the associated automatic transmitter, which connects that transmitter to the push-button turret; and depressing the proper destination push button on the turret panel. No further attention is necessary until the next message arrives.



Photograph 8-10,90

Figure 2. Control panel may carry 125 lamp and push-button units in various colors

Space is provided in the top front section of a cabinet to mount up to six automatic numbering machines in a row. The two end numbering machine positions are normally assigned to the sending side of the circuits terminated in the cabinet. The other positions can be used for selectorized way stations which require more than one numbering machine.

Other features of the cabinet include a motor-driven tape winder for sent tape, number sheet holders, and all necessary switches, buttons, lamps, and safeguards to provide complete control and supervision of the system. All of the relays, rotary switches, wiring, and other apparatus for

operation of each cabinet are completely housed in each individual unit thus eliminating the need for separate housing

Printer-Perforator

The printer-perforator is permanently connected to the receiving line and all incoming message tapes (Figure 3) are fed directly into an associated automatic transmitter In order to get the complete message through the automatic transmitter, if there is no subsequent message to furnish the necessary tape loop, each printer-perforator is equipped with an automatic noninterfering tape feed-out Although the feed-out cycle can be started

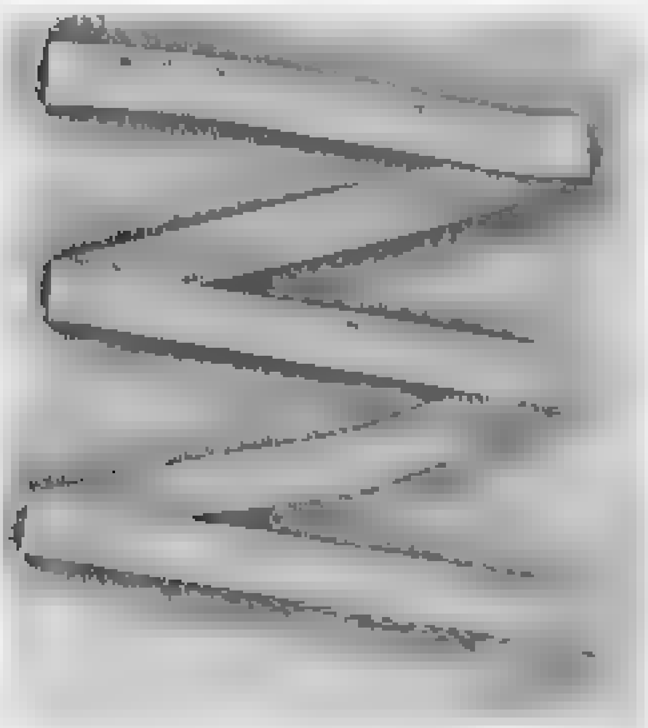


Figure 3. Western Union's "chadless" printer-perforator tape

manually, it is started automatically upon the receipt of the message-ending function "Carriage Return," "Carriage Return," Letters," followed by a tight-tape condition at the automatic transmitter

The automatic transmitter, two of which may be seen in the lower left of Figure 4, is equipped with a tape sensing or reading mechanism. Upon recognizing the message-ending function, the transmitter idles through the "Letters" characters, provided by the tape feed-out, until a tight-tape condition results or until the first character of the next message reaches the pins of the transmitter The message is then in a position for immediate switching and a lamp lights to alert the operator that a message is waiting

Automatic Message Numbering

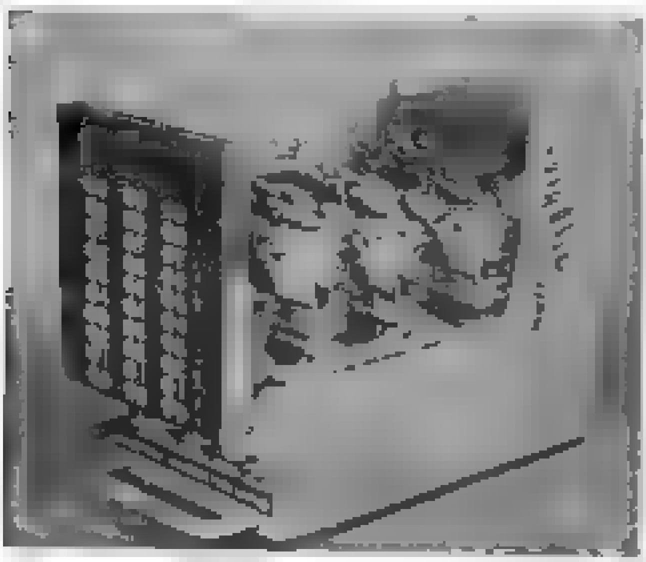
As a convenient means of identifying and safeguarding of messages (Figure 4), a number sequence together with other fixed identifying characters is automatically transmitted preceding every message switched at the center. This feature is obtained by the use of automatic numbering machines (Figure 5) and associated

Photograph H-1955

Figure 4. Automatic numbers and tally sheets safeguard every message

apparatus. The numbering machine is designed to transmit the office call, channel letters, or other identifying characters, together with consecutive numbers from 000 through 999 Features include a fast reset circuit, individual switches for rapid setting of the hundreds, tens, and units digits,

and a direct-reading register panel which, by means of neon lamps, indicates the number of the last message transmitted.



Photograph E-9459

Figure 5. Automatic message numbering machine

A Type 7014 automatic numbering machine is used on trunk circuits and way circuits with preselection or no selection. Preceding each message, this machine automatically transmits an office call, channel letters, and the number of the message.

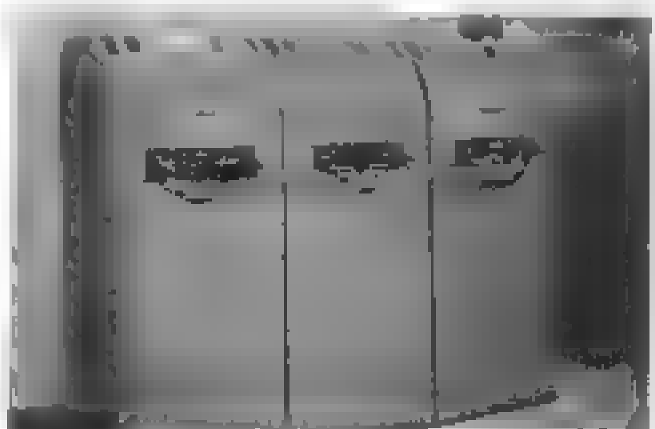
For operation on way circuits equipped with selectors, the Type 7298 automatic numbering machine is used. This machine is arranged to transmit eight fixed call letters, namely, A, D, H, L, N, R, S, and Z in the sequence listed or, in their place, the letter X. Up to eight selectorized stations with one letter assigned to each station and an "ALL" button may be connected to one way circuit. The same call letter sequence is used for other way circuits.

Preceding each message sent from the center, the numbering machine automatically transmits one or more call letters representing the stations desired, and the letter X in place of the call letters of unwanted stations. For example, if a message is to be directed to the station represented by the letter H, the machine transmits XXHXXXXX-012K "Space." "012" is the number of the particular message and "K" represents the channel designation letter of the circuit. The "Space" function serves to lock out uncalled stations so that the message is copied only by the selected station or stations. All stations will copy the selection sequence and the number, before the uncalled stations are released from the circuit. This arrangement permits all stations to maintain a sequential record of all message numbers.

An alternate method of automatic numbering on selective way circuits is to assign a Type 7014 automatic numbering machine to each way station. Each station then has an individual number sequence and does not copy the numbers of other way stations on the circuit.

Number Record Cabinet

The number record cabinet (Figure 6) contains a teleprinter and associated equipment. The number, the destination, the originator, and the originator's number for every message switched are recorded on the teleprinter. This record provides a completely pertinent, readily available account of each message passing through the switching center. Two number record cabinets are normally required for each group of 25 sending circuits but, if a large number of extremely short messages is contemplated on the system, at least three cabinets per 25 circuits will be necessary.



Photograph E-9737

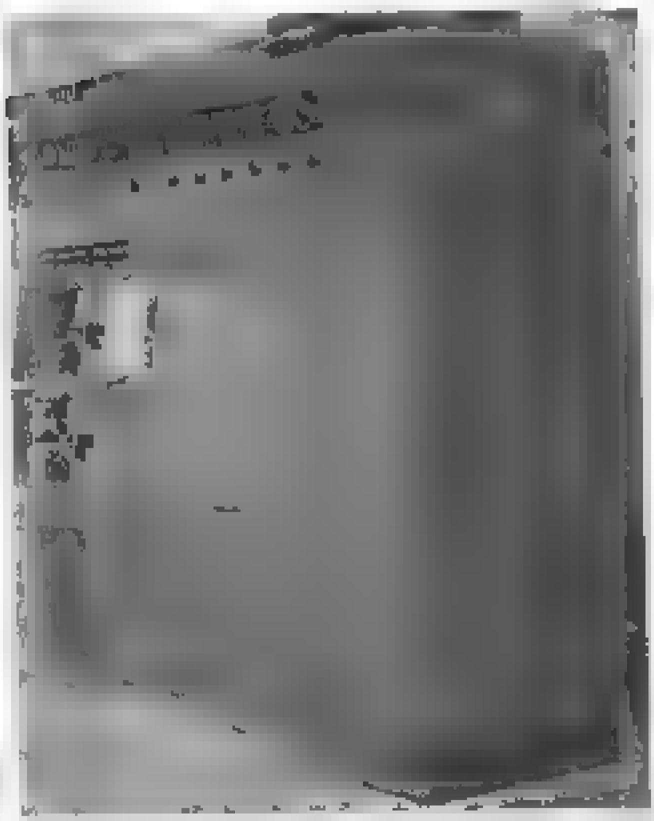
Figure 6. Number record cabinets automatically tally essential data on every message switched

"Spill-Over" Positions

A "spill-over" is a receiving position in the switching cabinet assigned to a cross-office circuit. Messages at any receiving

position destined to a closed-out circuit or to a closed station may be switched to the spill-over position. When the circuit is restored, or the closed station reopens, the messages are then switched from the spill-over position.

Local tape preparation and receiving equipment is required in the switching center to provide for incoming and outgoing supervisory notes and service traffic A receiving-only teleprinter, with an assigned push button at the switching turret, may be used for incoming traffic. A manual perforator is used to prepare local tapes for transmission which may be sent from any idle position in the switching aisle. A Type 19 automatic sending and receiving set can also be used, replacing both the teleprinter and the manual perforator The tapes prepared by the Type 19 set may be sent from any idle position, or the sending circuit of the Type 19 set can be permanently wired to a receiving position in one of the reperforator switching cabinets



Photograph B-9730

Figure 7. Equipment cabinet (center) and panel (right) match style and finish of switching cabinets

Automatic multichannel selection is built into the Plan 54 Switching System and, if applicable provides automatic load distribution of messages switched to destinations served by two or more sending circuits or channels.

Equipment Cabinet

A cabinet similar in size and appearance to the reperforator switching cabinet contains equipment common to the switching center Only one such cabinet is required and it is usually located at the end of a row of cabinets.

The end panels are metal housings used to enclose left and right ends of the switching cabinet rows, illustrated in Figure 7 A switchboard (Figure 8) is provided to terminate wire facilities and equipment on a cordless basis. The jacks permit testing, patching, and emergency swapping of equipment and facilities. A test table is furnished for the use of maintainers. Means are provided at this table for testing, repairing and monitoring all equipment and facilities in the switching center

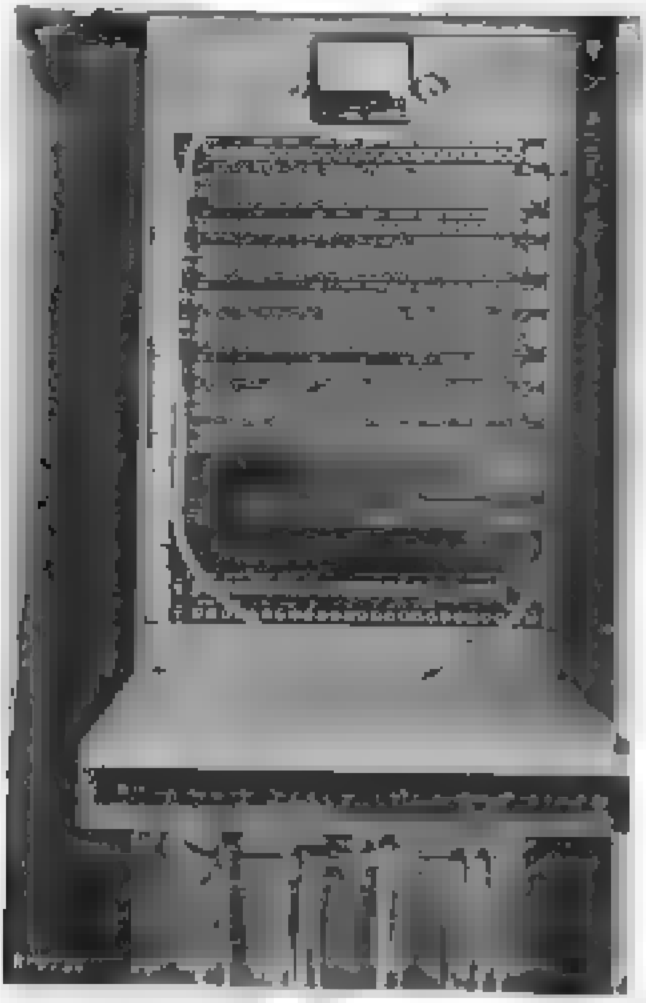
OPTIONAL FEATURES

The Plan 54 Switching System has been designed to include provisions for any or all of the following optional features

Master Sending

When the switching center is provided with master sending, transmission of a message from a single tape to as many as 100 destinations is made possible. Equipment necessary for master sending is contained in a master switching cabinet (Figure 9), and a master record cabinet The master switching cabinet is very similar in appearance to the reperforator switching cabinet. The master record cabinet contains a teleprinter and associated apparatus for recording the automatic numbers sent to each sending line and the complete text of all master messages.

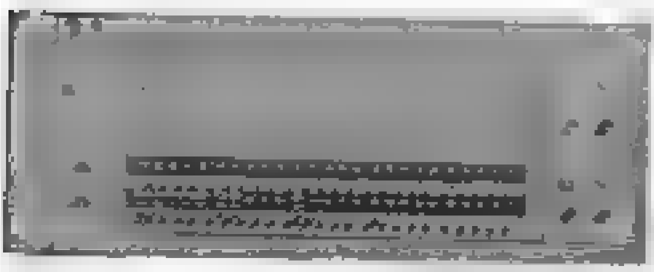
A multiple-address message is handled by switching the message from its incoming receiving position to the master send position The sending pattern is set up at the master send position by depressing all desired push buttons. Upon depressing the "MX" start button, the message is sent



Photograph R 9715

Figure 8. Switchboard facilitates testing and interchanging circuits and equipment

simultaneously and automatically to all selected circuits and stations. One master record cabinet is required for each master send pattern. The push button panel may be divided into two groups or patterns so that part of the push buttons are assigned to the top and the remainder to the bottom master sending position. In such cases the push-button assignments may be the same or different from the assignments on the Type 7000 cabinets.



Photograph R 10 151

Figure 9. Master switching cabinet panel is similar to regular switching panels but this cabinet can send to up to 100 destinations simultaneously from one tape

Multiplier Positions

These positions consist of two or more receiving positions wired in series with a cross-office circuit. The result is reproduction of an incoming message on two or more tapes. The new tapes may then be switched individually to different circuits. "Dual" positions (two tapes) and "triple" positions (three tapes) are the most widely used multiplier positions. Multiple address messages with only two or three different addressees are easily handled without resetting the original tape for the second and third addressee or tying up the master send positions.

"Flip-Flop" Receiving

The top and bottom receiving positions of a Type 7000 cabinet may both be connected to a very busy receiving circuit. The messages will then be received on the upper and lower printer-perforators alternately to increase the switching rates. The message-ending function controls the automatic flip-flop switching feature between the upper and lower positions.

Tape Repeater Cabinet

A tape repeater position (Figure 10) consists primarily of a printer-perforator and an automatic transmitter. Auxiliary equipment includes automatic tape feed-out on the printer-perforator, a tape accumulator to store unsent tape, a motor-driven tape winder for sent tape, and all necessary switches, indicating lamps, and safeguards. Two positions, each identical and mounted one above the other, are housed in a tape repeater cabinet.

Switching of messages to circuits equipped with tape repeaters is accomplished in the normal manner. The message, however, instead of being sent to the line, appears first at the printer-perforator in the tape repeater. The message tape is then fed continuously from the printer-perforator into the automatic transmitter, and the message transmitted to the line. On singly-operated circuits, tape repeater positions will be provided with a timer which stops transmission from the switching center when outstations send to the line.

Flip-flop sending can be provided by connecting two or more tape repeater positions to the same circuit. Transmission to the line is evenly distributed among these positions. If desired, any position can be arranged to be given precedence over another to provide a means for handling urgent messages. Two push buttons, a priority and a routine button, are provided on each reperforator switching cabinet for circuits so arranged.

Effective doubling of the switching rate to singly-operated two-way circuits is the major advantage of a tape repeater. Without a tape repeater, messages cannot be cleared from the switching aisle while an outstation is sending to the switching center. With the installation of a tape repeater, however, messages may be cleared from the switching aisle when either the circuit is busy, the circuit is closed out, or the receiving stations are closed. When the circuit becomes available, all messages in the tape repeater are automatically transmitted to destinations.

While tape repeaters are not necessary on duplex trunk circuits, they can be used to advantage for "flip-flop" or alternate sending from two tape repeater positions, when the volume of messages or conditions warrant.

Photographs P 10,053 and P 10,055

Figure 10. Tape repeater cabinet (left) helps to clear messages from incoming lines, can send out continuously

Control cabinet (right) includes auxiliary equipment for two duplex way circuits

Duplex Way Circuits

Duplex way circuits can be readily integrated into a Plan 54 Switching System. A duplex way control cabinet, Figure 10, houses the additional equipment required for two duplex way circuits.

Teleprinter tie lines can be assigned regular receiving positions and push buttons in the Plan 54 System and are recommended for rapid refile of "off-line" telegrams. This provides a direct connection to Western Union's nationwide reperforator system for public messages.

The Plan 54 Private Wire Switching System is versatile and readily adaptable to satisfy special requirements and provide each user with "custom-built" private communications.

Telefax Test Chart D&R 111655

EVER SINCE the adoption of facsimile operation as a method of telegram handling, Western Union engineers have sought a reproducible test chart comprising suitable analytical patterns for completely testing the performance of such equipment and its associated circuits. Early attempts to reproduce test patterns by photographic methods failed because of distortion due to shrinkage or stretching during the development process. Only a small percentage of copies of rather simple designs produced photographically were acceptable for laboratory requirements. Quantity reproduction for wide distribution of the material appeared out of the question, except for some form of dry printing.

Investigation of the problem indicated that letter-press printing, carefully performed, might be satisfactory. Several special branches of the printing art were involved. A top-flight photoengraver undertook the manufacture of printing plates to accurate dimensions from line drawings made by Western Union draftsmen. A creative typographer made perfect plates of letter and numeral characters needed for a portion of the chart. A difficult repetitive bar pattern was made to exacting dimensions in Western Union's model shop. Altogether a total of seven separate plates were assembled and locked together with great precision by the typographer, so that uniformity of printing over the entire area could be insured. A printer undertook the final printing from the original copper engravings, exercising the care necessary to produce 20,000 perfect copies without damage to the plates. The copies were printed on 8-1/2- by 11-inch sheets of good quality clay-coated white paper.

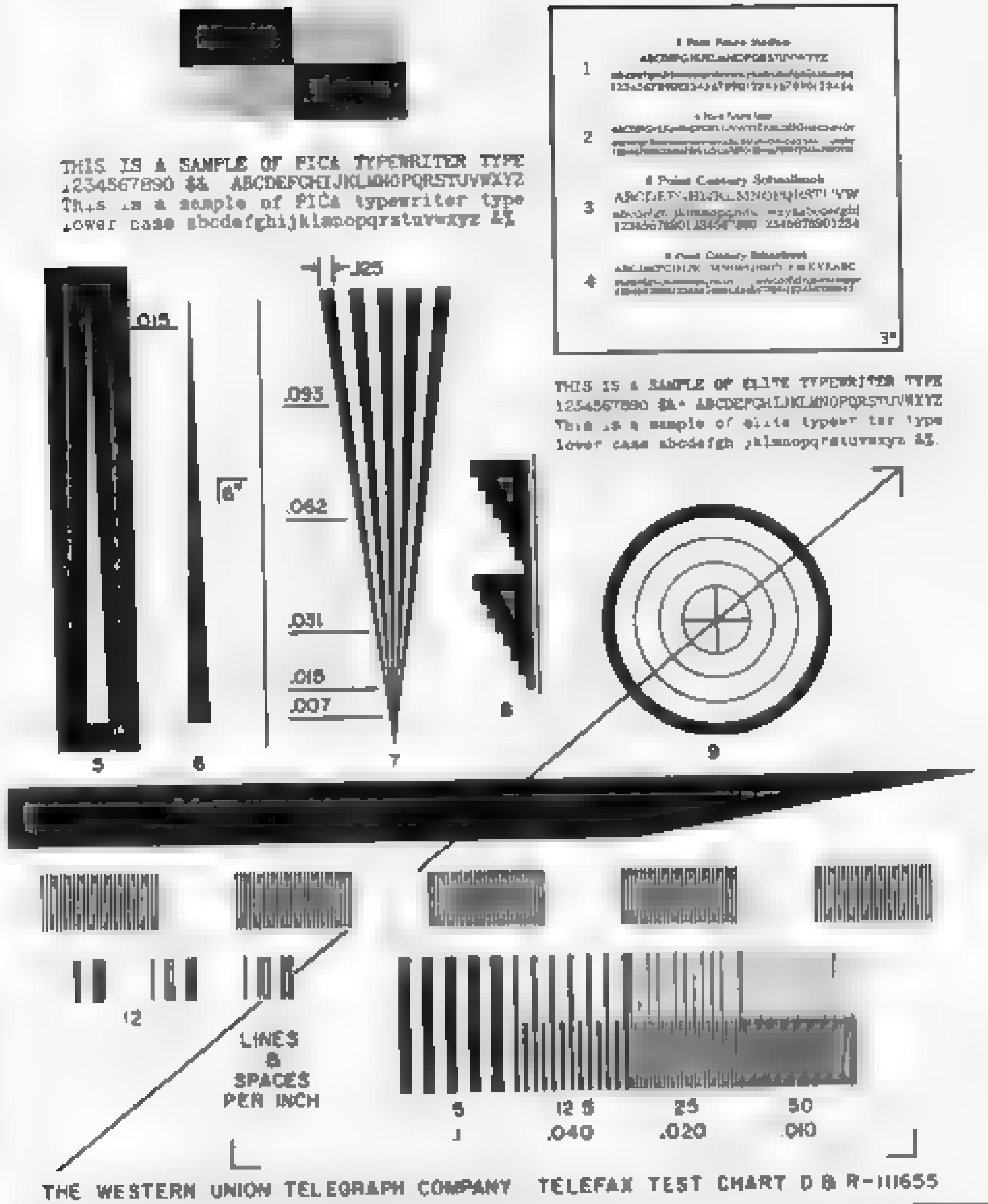
As a result of this combined effort, Facsimile Test Chart D&R 111655 produced in large quantities contains test patterns for both laboratory and field use. It is suitable for use by engineers, maintenance supervisors, technicians and maintainers for making spot checks or complete over-all performance checks of facsimile equipment. It is equally useful in checking electrical and mechanical adjustments and evaluating circuit transmission characteristics. The test chart is not intended for use in demonstrating equipment to patrons. It contains patterns of material that machines designed for business correspondence cannot be expected to reproduce well.

The quality of facsimile transmission and recording is sometimes described in terms of legibility of various sizes of print. The test chart therefore contains samples of pica and elite typing as well as 6- and 8-point print. Our regular facsimile equipment employing 100-line-per-inch scanning should reproduce satisfactorily the pica and elite type samples under all normal conditions. Acceptable reproduction of 8-point Century Schoolbook (Item 3) should also be expected under most conditions. Reproduction of 8-point Futura Medium (Item 1) may be expected to be marginal, and reproduction of the 6-point type sizes (Items 2 and 4) would be expected to be unsatisfactory on 100-line-per-inch equipment.

Western Union engineers are concerned with various factors which combine to produce the legibility results. The chart provides them a means to evaluate many of these factors. It comprises dimensional figures and patterns of various shapes, and a density step pattern screened at 133 lines per inch. The density steps are approximately 10, 20, 60 and 100 percent of full black. This density pattern is useful in determining when contrast and recording levels are correctly adjusted. It is not intended for use as a gray-scale for checking or setting up preamplifier or linearity. In systems set up for linear output to the stylus, such as the Letterfax and Ticketfax, each of the four density steps should be distinguishable on the recorded "Teledeltos"* copy. With nonlinear systems such as the Desk-Fax, the darkest of the gray shades should record as full black, the next lighter shade as a dark gray, and the lightest shade should be barely visible on a "Teledeltos" recording.

The negative and positive wedges (5 and 6) and the multiple wedge (7) are useful in determining resolution capability; the step pattern (8) is useful in determining voltage regulation and recovery time in power supplies and amplifiers; and the circle pattern (9) shows at a glance any large errors in index of cooperation and nonlinear line feed or scanning. The wide horizontal bar just below these patterns is used to determine the time required for d-c restoration or clamping in some modulation systems. Below this bar are five groups of line patterns arranged so that they will produce a repetitive oscilloscope pattern, by means of which the signal envelope may be observed and rise and decay times checked.

*Registered Trademark W. U. Tel. Co.



Pattern 12 is useful in checking circuit transmission characteristics and the effects of distortion-correcting networks. At the lower right are blocks of uniformly spaced lines with the number of lines per inch and line widths indicated, useful in determining resolution. These line blocks together with other vertical lines on the chart may be used in checking jitter and skew. The 3-inch square (around Items 1 to 4) and the 6-inch square (indicated by the corners only) may be used for accurately checking index of cooperation. A diagonal line across the lower half of the chart will show irregular line feed and/or nonlinear scanning.

The configurations and layouts of the chart resulted from the cooperative efforts of the several engineering research groups concerned with facsimile.

The accompanying reduced illustration of the chart is not suitable, nor intended, for test purposes.—C. U. HARTLE, Engineer, Systems Planning

CLIFFORD H. CRAMER, Assistant Radio-Wire Transmission Engineer

Submerged Telegraph Repeaters Come of Age

Since 1950 Western Union has placed underwater amplifiers in service on all of its long nonloaded ocean cables in the North Atlantic thus providing a substantial increase in transatlantic message capacity. Although submerged repeaters have been employed in short telephone cables for many years, Western Union was the first to develop and install deep-sea telegraph repeaters. A report covering operating experience, design modifications and the reasons for design changes is of interest.

THE FIRST installation of a submerged repeater in a transatlantic cable in September 1950[1] was also the first application of underwater electronic equipment in submarine direct-current telegraphy. That repeater, in transmission tests and trial operation on Western Union's 1PZ cable, extending 2154 nautical miles from Penzance (PZ), England to Bay Roberts, Newfoundland, increased the message capacity of the cable to more than three times its previous maximum. At the same time a substantial improvement in signal quality and operating stability was also attained. On the basis of those results plans were immediately initiated for further development of the repeater design and for installations on six of Western Union's transatlantic nonloaded cables.

Repeaters Double Western Union's Transatlantic Message Capacity

This North Atlantic cable plant comprises four nonloaded cables, terminating at Valentia, Eire, and Hearts Content, Newfoundland, one of which has not been equipped for repeater operation; three nonloaded cables and one permalloy loaded cable terminating at Penzance, England, and Bay Roberts, Newfoundland. Of the nonloaded cables included in the repeater program, five were originally laid in the period 1873 to 1894, and one in 1910. The length of the shortest is 1847 nautical miles; that of the longest, 2180 nautical miles. In 1950 the nonloaded cables provided 13 one-way printing telegraph channels with a total capacity of 570 words per minute; the loaded cable, 8 one-way channels, 400 words per minute.

The 1PZ repeater was picked up early in 1951, modified and reinstalled in June 1951. In the 3-year period to July 1954 the repeater system was installed on the other five transatlantic nonloaded cables and in addition on a coastwise cable between Hammel (Rockaway Beach), New York, and Bay Roberts. Of the transatlantic sections, four are equipped for reversible operation, each having a repeater inserted off the British Isles for eastward operation and one off Newfoundland for westward operation, and two have one repeater each for eastward and westward operation respectively. The coastwise cable has a westward repeater. Each repeater includes a switching device controlled from the near or receiving cable station by which a repeater is inserted in or disconnected from the cable circuit as required to establish the desired directional pattern of operation. The repeaters are located at cable distances from shore ranging from 63 to 346 nautical miles and in depths of 242 to 1240 fathoms.

A potential capacity of 32 one-way channels, 1600 words per minute, had been predicted for the six nonloaded transatlantic cables in repeater operation. This goal was realized during 1955. Including the loaded cable, the total capacity of these cables, now 40 one-way channels, 2000 words per minute, is double that available in 1950.

The Laboratory Goes to Sea

Satisfactory performance of electronic equipment on the bottom of the ocean, 100 to several hundred miles from shore and in depths as great as 1240 fathoms,

requires standards with respect to life, stability and reliability of a higher order than can be justified for readily accessible land-based equipments. Pioneering in such a venture poses many new problems and some of these are not anticipated initially. During the course of the development, the urgent demand for additional transatlantic telegraph capacity for the Armed Services took precedence over a normal program of development and engineering. In effect the laboratory was expanded to include the North Atlantic Ocean. The present repeater design has thus evolved through several stages as a result of field experience, paralleled by continuing laboratory development. In the interim the intermediate designs served to meet the most urgent demands for facilities.

The first model of the repeater is still in operation, more than five years since installation, with no evidence of deterioration. As described in detail in an earlier paper,[1] Repeater No. 1 is housed in a rectangular case. Originally the 3-stage push-pull amplifier utilized Type 5693 pentodes and several spare vacuum tubes were provided. A switching device, operated by trains of 60-cycle alternating current, served to connect and disconnect the repeater and to substitute spare tubes in various combinations in the event of failures. A piston-cylinder arrangement formed part of the pressure-equalizing system by which the hydrostatic pressure of the sea water was transmitted to oil within the repeater case. This repeater was modified in several respects prior to reinstallation. A complete spare amplifier was provided instead of spare vacuum tubes. This facilitated selection and matching of tubes and simplified the switching circuit. The tubes were changed to Western Electric 310-A pentodes because of somewhat better and more uniform characteristics and the probability of substantially longer life. Metal film resistors which had deteriorated badly during the first installation period were changed to compressed carbon resistors. The operating mechanism of the switch was changed to a form involving use of both a.c. and pulsed d.c. The piston and cylinder were replaced by a rubber bellows because of corrosion. All of these changes have been retained in later models of the repeater with the exception of the switch operating device.

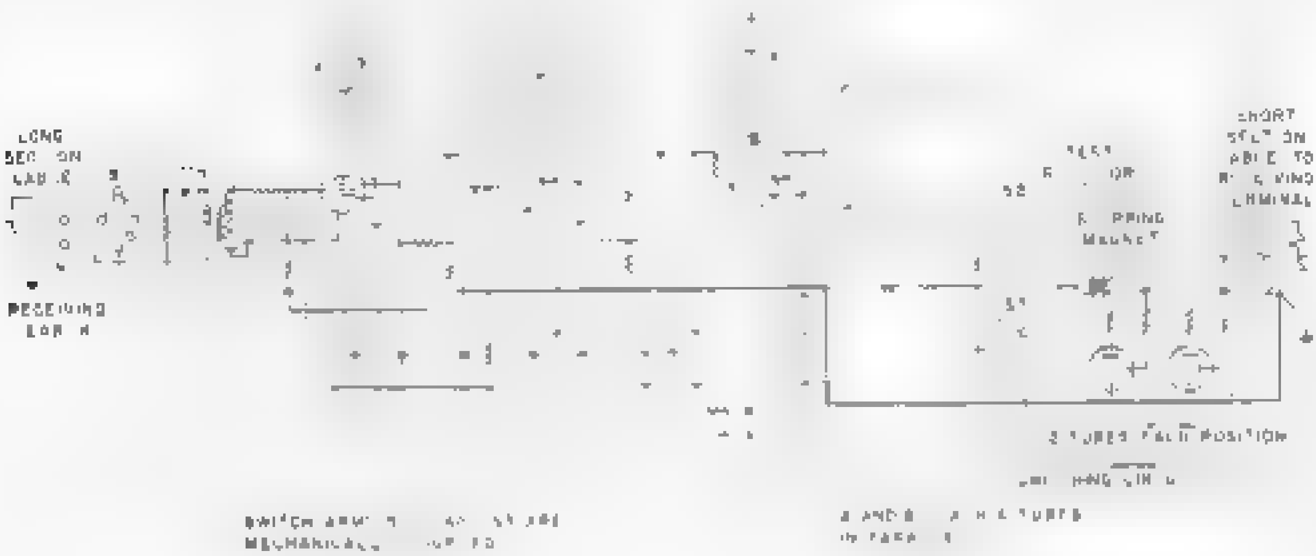


Figure 1. Schematic of latest repeater circuitry

As the repeater construction and installation program progressed, a number of other changes, both in circuitry and physical design, were incorporated. The total number of repeaters required was small so that it was feasible to apply essentially custom design and construction to individual repeaters as further development results and field experience became available. A total of 15 repeaters were constructed. The last four are alike in all important details and may be regarded for

the present as embodying a "standard" design for single repeater applications, although they are individually adjusted for specific electrical characteristics. The following description applies to this design.

Circuitry, Electrical Characteristics and Physical Design of Latest Repeaters

The repeater amplifier, as shown in the schematic diagram, Figure 1, is a 3-stage single-sided amplifier, with six tubes in multiple in the third stage to provide adequate signal output level. A second or spare amplifier is provided. With the exception of heaters, corresponding tube elements of the two amplifiers are connected in multiple, stage by stage. The two heater circuits, each with eight tubes in series, terminate at separate switch positions and one or the other may be selected and powered as desired. The vacuum tubes are 310-A pentodes; those in the third stage are connected as triodes. Common to both amplifiers are the preamplifier input and signal-shaping network, the interstage resistance-capacitance coupling, the decoupling and negative feedback networks. The output impedance with six tubes in multiple is suitable for direct coupling to the cable. This makes unnecessary the use of an impedance-matching output transformer and thus avoids certain distortions of signal transients which are difficult to correct elsewhere. The plate circuit is connected to earth, the cathode or negative side of the amplifier to the cable conductor. The repeater power supply[2] at the receiving cable terminal is poled minus to cable and plus to earth. This circuit arrangement is used to minimize electrolytic corrosion of the repeater case and the adjacent cable armoring. Power is supplied to the repeater at 150 to 160 volts and 0.34 ampere of which 0.30 ampere is heater current. Automatic controls at the terminal maintain the current at constant level.

The repeater switch is a 3-deck rotary unit stepped by a ratchet mechanism and electromagnet operated by d-c pulses. The switching function is made selective by use of cold cathode gas triodes. These tubes are permanently connected, anodes to cable, cathode to earth, and do not fire when the repeater is powered. To fire the tubes and operate the switch, pulses of opposite polarity (plus to cable) are transmitted from the terminal. Switching potential and current levels at the repeater are within the range 145 volts and 25 milliamperes to 175 volts and 35 milliamperes. A copper oxide rectifier effectively isolates the amplifiers from the switching circuit so that during switching operations the amplifiers are subjected only to very low voltages and the switching tubes are not shunted directly by the low resistance heater circuit.

By means of the switch these conditions may be set up: (1) Either of the two amplifiers inserted for operation with repeater; (2) Cable connected through for operation in either direction without repeater or for operation in reverse direction with repeater on those cables equipped with two repeaters; (3) A test resistor equivalent to the "hot" resistance of the heaters, inserted in series with the rectifier and the normal heater circuit resistor, permitting the condition of heaters and rectifier to be checked by measurements at the terminal; (4) Cable open and repeater disconnected, with exception of the switch circuit which is permanently connected to cable.

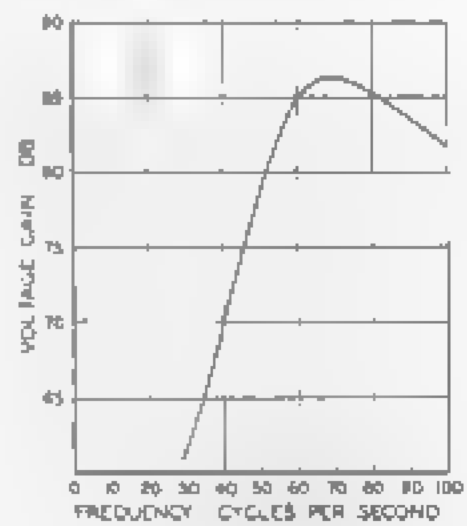


Figure 2. Typical frequency-gain characteristic of repeater for 6-channel 1800-lpm operation

Shown in Figure 2 is a frequency-gain characteristic typical of repeaters designed for 6-channel multiplex operation, 50

words per minute per channel. Since 5-unit Baudot code is used, the dot frequency is 75 cycles per second. The "suppressed singles" system of transmission, standard on Western Union cables for a number of years, is employed also in repeater operation. The speed of transmission is such that the dots or single-unit pulses are received at a level much too low for satisfactory operation. The repeater and the terminal amplifiers and networks provide optimum reception for "doubles" (2-unit pulses) and longer signal pulses. The missing dots are interpolated or re-inserted synchronously by the receiving regenerator. The frequency characteristic illustrated is thus suitable for operation at a "doubles" frequency of 37.5 cycles per second.

Experience has shown that the frequency-gain characteristic of the repeater is not highly critical and the allowable tolerances are not difficult to meet in production. Although transmission parameters differ somewhat from cable to cable, in practice the Western Union nonloaded cables in repeater operation fall into two speed categories; 6-channel, 75-cycle circuits and 4-channel, 50-cycle circuits. It has been found that a repeater designed for 6-channel operation will provide satisfactory, although perhaps not optimum, performance in any of the five cables in that category. Similarly, 4-channel repeaters can be used interchangeably in the other two cables. This desirable condition, which minimizes the requirements for spare repeaters, is in large part possible because the gains, levels and signal shaping networks at the cable terminals are adjusted specially for each specific combination of cable and repeater and can accommodate a moderate range of transmission characteristics between transmitter output and receiver input.

The physical design of the present repeater differs principally from earlier models in that the case is a "double-end" type with input and output cable connections at the opposite ends, replacing a "single-end" type in which all connections entered at one end. The "double-end" design, Figures 3 and 4, is superior, particularly for deep water installations, since

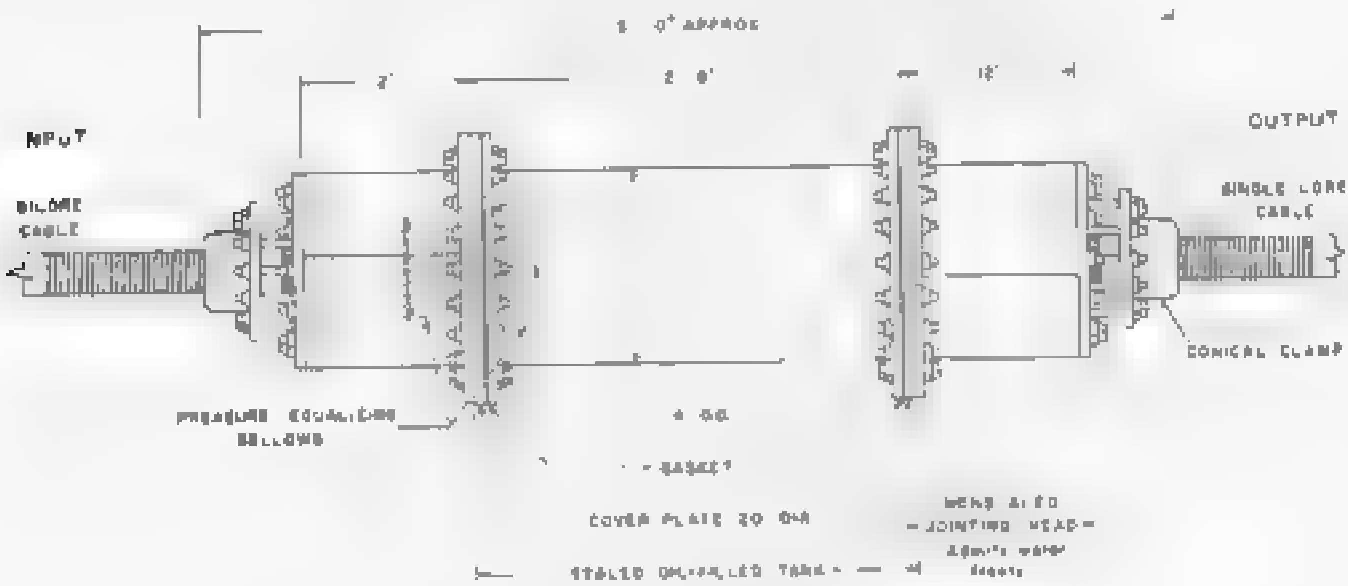
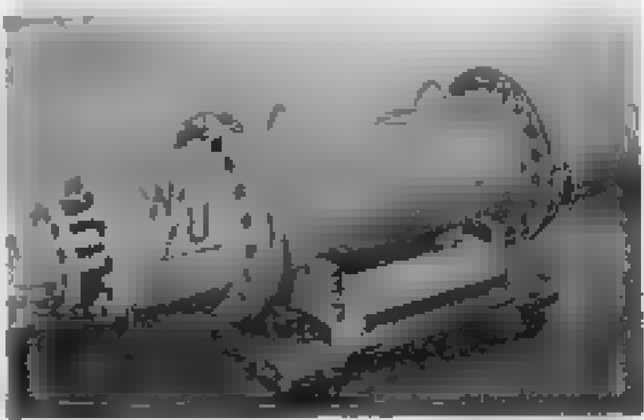


Figure 3. Scale drawing of "double end" repeater case



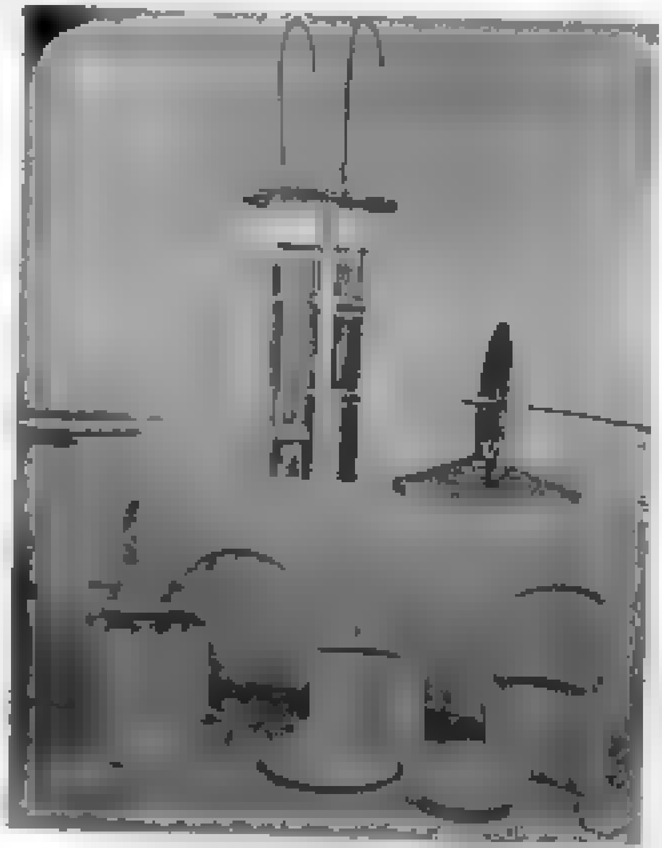
Photograph R 9987

Figure 4. "Double end" repeater case

the normal untwisting and twisting of cable armor wires under tension is not greatly affected in lowering and raising a repeater to and from the ocean bed. In the installation operations aboard ship the armored cable ends are brought into the jointing heads where the cores are spliced to the stub core leads of the repeater. The armor wires are turned back along the cable through a serrated conical clamp and secured to the cable.

Complete parts of a repeater ready for final assembly are shown in Figure 5. The cylinder housing the repeater, the cover plates, and the semicylindrical sides of the jointing heads are fabricated of cold rolled steel with the flanges welded in place. The conical clamps are steel castings. The two cable leads and one earth lead are short lengths of single-conductor polyethylene core which are pressure-sealed in glands mounted on the cover plates. The glands, all nuts and bolts used as fastenings, and small auxiliary metal parts are made of corrosion-resistant monel metal. All steel surfaces exposed to sea water are coated with zinc to inhibit corrosion. The gaskets between the cover plates and the flanges of the case are made of a type of synthetic rubber compatible with oil and sea water.

Following assembly, dry nitrogen is circulated through the repeater to remove moisture. The nitrogen and remaining air are then removed by vacuum pump, and the repeater is filled, under vacuum, with an oil having low vapor pressure. Hydrostatic pressure within the repeater is maintained at or near the external pressure on the case: atmospheric pressure before installation, sea-bottom pressure after installation. The pressure-equalizing device consists of two bellows mounted on the top cover plate as shown in Figure 3; a metal bellows on the underside of the cover, and thus surrounded by the oil within the case, and a synthetic rubber bellows on the outer side of the cover and within the jointing head. The jointing head is not sealed and freely admits air or water. An opening in the cover connects the interiors of the two bellows which are also filled with oil. With any change of external pressure, the bellows contract or expand and automatically change the pressure within the case by a like amount. Equalization of external and internal pressures greatly reduces the difficulties of sealing the case and glands against entrance of sea water.



Photograph R-10,072

Figure 5. Exploded view of repeater chassis and case

A repeater chassis of the latest type, completely assembled and wired, is shown in Figure 6. The framework and shelves of the chassis structure are made of aluminum to minimize weight. Where feasible, filler blocks of aluminum are mounted in space not occupied by repeater components so as to reduce the quantity of oil required to fill the repeater. The oil has a relatively large volumetric temperature coefficient which is an important factor in determining the size and expansion requirements of the bellows. The bellows capacity must be such as to compensate for residual voids or air pockets resulting from incomplete filling with oil as well as for changes of volume.

Some of the repeater components are mounted directly in the oil and are thus subjected to sea-bottom pressures. These are the capacitors which are a standard

Photograph R-9509

Figure 6. Repeater chassis, completely assembled and wired

commercial paper-foil type filled with mineral oil; the wire-wound resistors—special mica card units used in input, cathode and heater circuits; and the input transformers. The other components—vacuum tubes, compressed carbon resistors, switch units and copper oxide rectifier—either cannot withstand sea-bottom pressures or are of doubtful compatibility with oil. Groups of these components, directly associated in circuitry, are made up as subassemblies and sealed in thick-walled cylindrical steel containers. Before final sealing, the containers are filled with dry nitrogen at or near atmospheric pressure. Each of four of the subassemblies, for example, includes four vacuum tubes and related carbon resistors. Other sealed units contain the switch, the cold cathode tubes and related resistors, the rectifier, and the feedback network resistors.

Construction and Production Testing of Repeaters

Numerous electrical and physical tests and several aging procedures are carried out in the course of repeater construction to assure quality of individual components and of subassemblies and complete repeaters. In the space available here mention can be made of only a few of these.

The 310-A Vacuum Tubes procured for use in repeaters are standard tubes, produced under the manufacturer's normal conditions of quality control and aging. The tubes are further aged for 2500 hours under simulated operating conditions and the tube characteristics are measured periodically. The purpose of this processing is to eliminate any tubes destined for early catastrophic failure—heater failures and short circuits between elements, to stabilize operation characteristics, and to disclose any having characteristics differing significantly from average. Finally, tubes with closely matching characteristics are selected for corresponding positions in the two amplifiers of a repeater. Rejection of tubes for all reasons as unsuitable for use in repeaters is less than five percent.

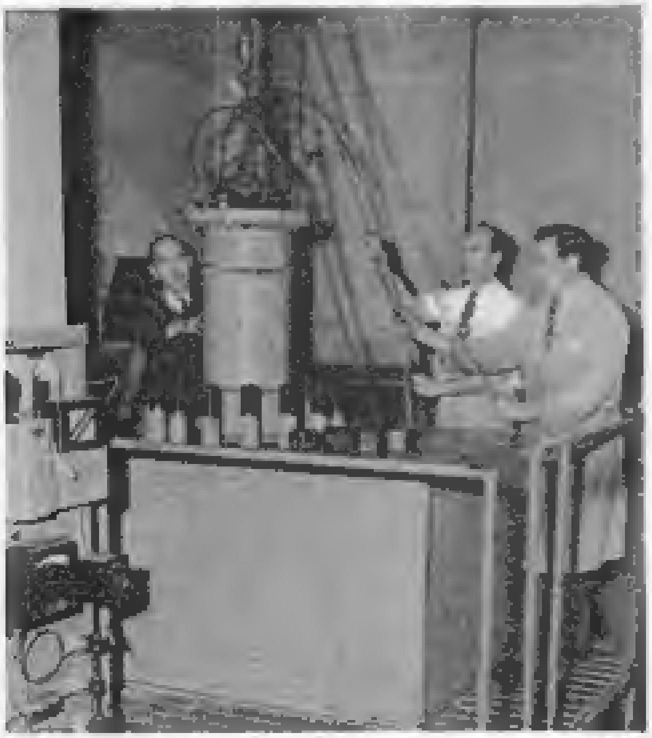
The compressed carbon resistors are individually tested for noise level in the frequency band between 20 and 200 cycles per second. An average of about 50 percent of those tested fall within a maximum acceptable limit of 0.1 microvolt per volt established for this purpose.

The oil-filled capacitors, rated at 600 volts d.c. working voltage, are mounted directly in the oil within the repeater case and thus in service are subjected to sea-bottom pressure both externally and internally. Acceptability for use in repeaters is determined by tests at pressures ranging from atmospheric to 6500 pounds per square inch. Temperature and pressure coefficients of capacitance are measured on 10 percent of each lot of capacitors. Other tests performed on all capacitors include: measurement of insulation resistance before and after subjection to pressure, with 500 volts d.c. applied; voltage breakdown tests at about double the rated working voltage; aging under pressure for 30 hours with 500 volts d.c. applied continuously. All containers are examined for evidence of physical damage caused by pressure, particularly leakage of oil and deformation of the containers. A deformed container indicates incomplete filling with oil during

manufacture or subsequent loss of oil by leakage. The rejection rate on capacitors is not more than two percent.

The subassemblies, before final sealing in containers, are tested for performance in the laboratory experimental cable circuit. After sealing, the units are tested for oil leakage under pressures up to 6500 pounds per square inch.

Frequency response, feedback, gain, and signal transmission characteristics of the repeater as a whole are measured at various stages of completion, and corrections are made as required to meet design objectives. Adjustments of certain feedback resistors are made when the chassis is otherwise completely assembled and wired. When satisfactory results have been obtained with the completed but uncased repeater, it is inserted in the case and tests are repeated before and after filling with oil. The additions of case and oil each have effects on electrical characteristics, principally feedback relationships, which can be predicted approximately and discounted. Occasionally the effects are such as to require removal of the repeater from the case for readjustments. Before oil is added the sealed case is tested for leaks by injecting nitrogen, with a halogen added, at 50 pounds per square inch. This is about five times the normal internal-external pressure differential. A leak detector, extremely sensitive to the halogen compound, is used to explore all external surfaces of the case, as well as glands and gasket seals, for evidence of leakage.



Photograph H-1605

Figure 7. Lowering repeater into high-pressure test tank for "sea-bottom" tests

Finally the repeater is immersed in water in a large tank, Figure 7, and tested under pressures up to 3000 pounds per square inch and at temperatures as low as 32 degrees Fahrenheit. The effectiveness of the seals against leakage of water, the operation of the pressure equalizer, and the electrical characteristics of the repeater are thus pretested at pressures and temperatures similar to those which the repeater will encounter on the ocean bed.

Let's Look at the Record

The introductory period of radically new and untried equipment in a communication system is quite likely to point the way to desirable improvements. When, as in this case, initial installations are made during the active development stage of the project, some essential modifications in circuitry, components, or physical design may also be uncovered. All of the repeaters constructed thus far, 15 in number, have seen actual service for periods of ten months to five years. Because of circuit troubles manifested in various ways, the first nine repeaters have been picked up and returned to the laboratory for modifications, some desirable, some essential, and then made available for further service.

Circuit troubles have been chargeable to repeaters in six of the nine instances. In Repeater No. 1, in its original form, all resistors not wire-wound were of a metal film type. During the first service period of that repeater, all of the metal film resistors deteriorated badly within a few months, the resistance values falling as much as 90 percent. The cause of these failures remains unknown; attempts to reproduce similar results in the laboratory were unsuccessful. Compressed carbon resistors were used in repairing Repeater No. 1 and in all subsequent repeaters. A

capacitor failed in Repeater No. 5 about three years after installation. The cause of failure of Repeaters 3, 4, 7 and 9 was water leakage. Sea water entered one of the cable entrance glands of No. 3 during installation causing an immediate short circuit from a cable conductor to earth. The gland design in that repeater, as well as in Repeaters 1 and 2, was such that the seal was subjected to full sea-bottom pressure.

Repeater No. 3 was repaired by installing glands of a type acted upon only by the differential pressure of the repeater. This was accomplished by extending the stub core through the gland and into the repeater. The stubs were insulated with polyethylene of greater molecular weight which is less subject to swelling in the presence of oil. Environmental cracking of polyethylene that may occur under stress after exposure to oil is not a factor here. The polyethylene within the repeater is unstressed and in any case it is completely surrounded by oil having excellent insulating properties. The basic principle of the new design has been used in all later repeaters. Water leakage into the interiors of Repeaters 4 and 7 caused failure of the copper oxide rectifiers, 15 and 10 months respectively after installation, and resulted in inoperable switches. In those early models the rectifiers were mounted directly in the oil and the presence of sea water apparently induced destructive electrolytic action. In Repeater 4 the evidence indicated probably faulty operation of the pressure equalizer but the exact nature of the failure was not established. Under sea-bottom conditions water was forced between gasket and cover plate or flange into the repeater. Leakage occurred through one of the glands of Repeater 7, probably as a result of improper adjustment of the gland just prior to installation of the repeater. A loss of insulation resistance occurred in the output connections of Repeater 9. The probable cause was leakage of a small amount of water, as evidenced by some corrosion products, but the location of the leak could not be established.

Repeaters 2, 6 and 8 were picked up because of intermittent circuit noise. These repeaters, when returned to the laboratory and tested, were found to be free of noise. However, certain cable conditions which affected low-speed operation in a minor and negligible degree assumed greater importance in high-speed repeater operation. Thus noise effects resulting from a variable condition of cable insulation or conductor on the input side of the repeater are greatly magnified because of the low signal level in the cable and the high gains in the repeater amplifiers. Similar variable conditions in the short cable section between receiving terminal and repeater, acted upon by the relatively high voltage and current required to power the repeater, may also generate excessive noise levels. Replacement of a section of old cable or possibly of an existing splice may be required to correct the trouble. A detailed physical and electrical history of each cable has been maintained for many years and this can well provide important clues. A cable with an extended previous history of noise and unstable duplex balance posed the most problems in conversion to repeater operation. The repeater was replaced on three occasions. Just prior to the third replacement in June 1955, two sections of old cable between the repeater location and the receiving terminal, totaling about 15 nautical miles, were renewed. Performance of the circuit since that time has shown substantial improvement.

In two instances a vacuum tube heater has failed in service. Failure of a vacuum tube interrupts circuit operation only until the spare amplifier is switched into circuit. One of these repeaters was picked up for other reasons; the other is still in service three years after the heater failure. The 15 repeaters contain a total of 240 tubes.

In retrospect, the record of the first nine repeaters reflects the urgency of installation and the conduct of laboratory testing on sea bottom. However, in the over-all cable system economy, the added expense involved in maintaining the early repeaters in operation was relatively unimportant and was quickly recovered. On the balance sheet it paid off. From a developmental viewpoint, much information normally obtained in the laboratory was in fact ac-

quired more rapidly through experience with the service installations. This experience unquestionably accelerated the further development carried on concurrently in the laboratory. Perhaps the best criterion of substantial progress and of justification for optimism is derived from the trouble-free performance of the last six repeaters since installation in 1953-54.

A Glimpse at the Future

Before this paper is published, first field trials of a tandem repeater system will be in progress. Two submerged repeaters in one of the transatlantic sections, at distances of 250 and 675 nautical miles from Bay Roberts, and two in the coastwise cable, 108 and 485 nautical miles from Hammel, are designed to provide 150-cycle (12-channel) operation westward, double the present speed of these cables and the highest speed attempted thus far in transatlantic telegraphy.

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